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# PLANT TISSUE TESTING

## II. A STUDY OF THE METHOD OF FOLIAR DIAGNOSIS[1]

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An examination of the chemical composition of plants in order to determine the availability of soil nutrients and thus, indirectly, the fertilizer requirements of a crop, has long been in use. Although in 1928, Salter and Ames (5), after due consideration of the problem, reached the conclusion that this method of approach was not practical, nevertheless, since that time, many investigators have continued their studies from various angles and have made considerable progress.

### LITERATURE REVIEW

At the present time, a variety of methods are available. These include relatively rapid tests on fresh plant tissue, the analysis of extracts of fresh tissue, the analysis of expressed plant sap, and the more accurate analyses of the dried plant or certain parts thereof, particularly the leaves. Among the last is a method of "foliar diagnosis" proposed by Lagatu and Maumé of France and further investigated by Thomas and Mack of Pennsylvania, though not utilized to any extent by other workers. Experimental results obtained by these authors were claimed to show that: (a) on homogeneous growth media and under the same external factors, morphologically homologous leaves (which will be of the same metabolic age) from plants of the same kind will give substantially the same chemical analyses (foliar diagnoses); (b) leaves from the same kind of plant grown on different media or subjected to different external factors will have, in general, different foliar diagnoses. If plants show responses (using development and yield as criteria) to different media or external factors, *e.g.* different fertilizer treatments, these responses will be systematically reflected in the composition of the leaves; (c) since foliar diagnoses are subject to variation due to external factors such as the weather, it is not possible to use the figures obtained from any one as absolute values. They may be used only in comparisons with those from other foliar diagnoses made on the same leaves from the same kind of plant grown under conditions such that all factors causing variation are rigidly controlled. These ideal conditions will naturally not be realized perfectly in field experiments, but control can be sufficiently close to make comparisons valid.

Lagatu and Maumé (2, 3) carried out two large scale field experiments with two kinds of potatoes on two widely different soil types. Analyses for nitrogen, phosphorus and potassium were made on the plants and the

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TABLE 1.—CORN PLANTS—AREA NO. 1

Mean Values for Treatments, Blocks and Sampling Dates

(Analytical results on moisture-free and silica-free basis)

| Treatment | % N | % $P_2O_5$ | % $K_2O$ | % CaO | % MgO | *Yield, lb. |
|---|---|---|---|---|---|---|
| Check | 1.66 | 0.78 | 3.69 | 0.94 | 0.59 | 14.59 |
| PK | 1.66 | 0.70 | 4.83 | 0.79 | 0.51 | 19.09 |
| NP | 1.79 | 0.48 | 3.46 | 1.03 | 0.52 | 23.56 |
| NK | 1.90 | 0.46 | 4.62 | 1.03 | 0.54 | 27.08 |
| NPK | 1.91 | 0.50 | 4.64 | 0.99 | 0.53 | 28.05 |
| 2NPK | 1.95 | 0.57 | 4.24 | 1.00 | 0.54 | 33.07 |
| 3NPK | 2.39 | 0.49 | 4.25 | 1.11 | 0.63 | 33.09 |
| N½PK | 1.77 | 0.45 | 4.54 | 0.96 | 0.50 | 27.09 |
| N2PK | 1.65 | 0.43 | 4.33 | 0.95 | 0.53 | 27.23 |
| NP2K | 1.65 | 0.48 | 4.87 | 0.93 | 0.50 | 24.23 |
| Necessary difference (P = 0.05) | 0.37 | 0.12 | 0.35 | 0.12 | — | 7.57 |
| Block 1 | 1.84 | 0.58 | 4.27 | 1.06 | 0.50 | 22.47 |
| 2 | 1.98 | 0.52 | 4.42 | 0.97 | 0.53 | 29.56 |
| 3 | 1.59 | 0.50 | 4.38 | 0.92 | 0.52 | 18.70 |
| 4 | 1.92 | 0.54 | 4.33 | 0.95 | 0.62 | 32.10 |
| Necessary difference (P = 0.05) | 0.23 | — | — | 0.08 | 0.05 | 4.78 |
| Sampling date 1st | 2.20 | 0.56 | 4.92 | 1.03 | 0.56 | |
| 2nd | 1.47 | 0.51 | 3.78 | 0.92 | 0.52 | |
| Necessary difference (P = 0.05) | 0.16 | — | 0.16 | 0.06 | — | |

*The yield data represent the total weights of ears plus stover per plot as harvested.

results were presented in three ways: (1) graphs were drawn showing the per cent N, $P_2O_5$ and $K_2O$ at each sampling date; (2) the sums of the percentages of the three, called the "total nutrition", were plotted against sampling date; and (3) the ratio $\%K_2O$: $\%N$ was used as an indication of the balance, or imbalance, of nutrition of the plant.

Examination of the results showed that, in these cases, the conclusions to be drawn from the foliar diagnosis were substantially the same as those to be drawn from the yield figures. In general, the percentage composition of the leaves reflected the fertilizer treatments of the soil, on which the plants were grown, at all sampling dates. The shapes of the "percentage composition-sampling date" curves were similar for similar treatments, but no relation was found between the slope of the curves and the developments or yields. High values for the total nutrition factors were associated with high yields with some exceptions which, however, were of value by indicating conditions of luxury consumption.

Work on the technique of foliar diagnosis was continued in the United States by Thomas and Mack. In 1937, Thomas (6) published a review of the method, with details of sampling procedure and a new way of expressing results. The use of the ratio $\%K_2O$ : $\%N$ as an indication of the balance of nutrition was rejected and the "NPK-unit", which took into account the

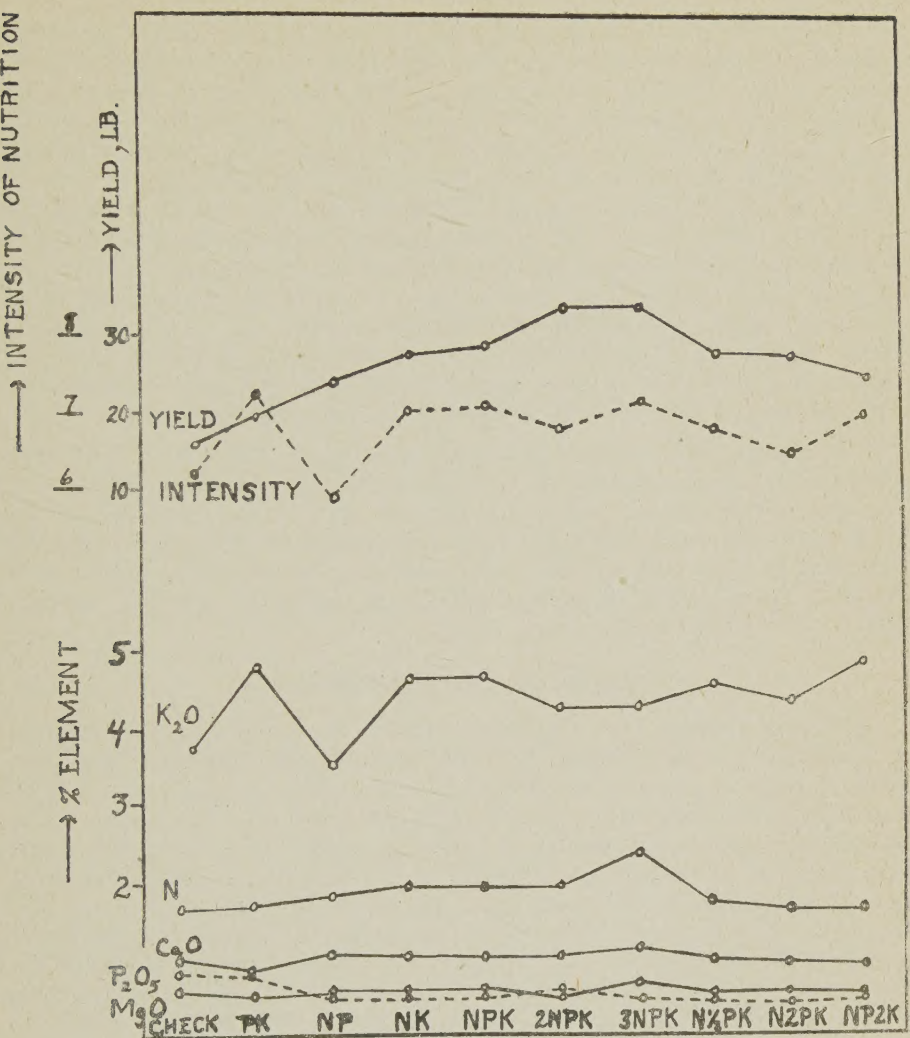


FIGURE 1. Mean per cent Composition, Yield and "Intensity of Nutrition"—Corn, *Area No. 1.*

amounts of the three principal fertilizer elements, was substituted. To calculate this unit, the amounts of N, $P_2O_5$ and $K_2O$ were first converted from percentages to milliequivalents. The three values so obtained were summed and the proportion of each present in the sample was then expressed as a percentage of this sum. The three values were plotted on trilinear graph paper. In the same way, the balance of nutrition with respect to any three elements might be studied with the aid of the appropriate unit, *e.g.* the CaMgK-unit. The slopes of the curves in the "sampling date-percentage composition" graphs were interpreted as indicating the "course of nutrition" of the plants, although the evidence obtained by Lagatu and Maumé threw some doubt on this interpretation. The change in the NPK-unit over the period of development was also interpreted as an indication of the "course of nutrition" of the plants.

From 1938 to 1944, Thomas and Mack published a series of twelve papers (7-18) describing experiments in which the method was applied under a wide variety of conditions with more or less success. In general, confirmation of the principles enunciated by Lagatu and Maumé was found. However, although in general there was association of high yields with high values of the "intensity of nutrition" factor ($\%N + \%P_2O_5 + \%K_2O$), there was no systematic relationship which was ever valid through the whole range of values. This is easily understood since, in all the above experiments, the amounts of $K_2O$ in the leaves were much greater than those of $P_2O_5$ and almost always greater than those of N. Moreover, these amounts varied quite considerably and, therefore, the "total nutrition" factor was, in effect, the index of the quantities of $K_2O$ present. Also, an over-abundance of one or more elements may raise the value considerably with no increase, or even with a decrease, in the yield of the plant.

In general, the positions of the average values of the NPK-unit were close to the points representing best yield when the yields were close, but there was no systematic relation between yield and the distances on the NPK-unit diagrams from the points of best yield, even when such distances extended in approximately the same direction. Here again, variation in the $K_2O$ content might be expected to disturb the values out of all proportion to their effect on the plant.

## DESIGN OF THE EXPERIMENT

An investigation into the application of the foliar diagnosis method was conducted on two areas of the fertilizer plots of the Chemistry Division, Central Experimental Farm, Ottawa, during 1945. The soil was a light sandy loam but area No. 1 had been under continuous cultivation for a number of years, while area No. 2 had been in sod for about 15 years and was ploughed and cultivated in the fall of 1944. Chemical examination of soil samples showed that area No. 2 had a considerably higher level of fertility than area No. 1, and this was confirmed by the better growth and higher yields obtained thereon. Area No. 1 consisted of four blocks of ten plots each and thus allowed for four replicates of ten fertilizer treatments, *viz.:* check, PK, NP, NK, NPK, 2NPK, 3NPK, N$\frac{1}{2}$PK, N2PK, and NP2K. Area No. 2 consisted of four blocks of eight plots each and thus allowed for four replicates of eight fertilizer treatments, *viz.:* check, PK, NP, NK, NPK, 3NPK, N3PK and NP3K. On each area the individual plots were 1/200 acre in size and the NPK treatment was equivalent to an application of a 4-8-10 fertilizer at the rate of 1000 lb. per acre, supplying 40 lb. N, 80 lb. $P_2O_5$ and 100 lb. $K_2O$ per acre. Treatments listed above showing 3N, $\frac{1}{2}$P, 2K, etc., supplied triple, half and double amounts of these constituents, respectively. Moreover, since the phosphorus was applied as superphosphate which contained about 28% CaO, every application of 80 lb. $P_2O_5$ was accompanied by about 110 lb. CaO. Potatoes, tomatoes and corn were grown on the plots of area 1, and potatoes, tomatoes and oats on those of area 2.

Corn leaves were collected on July 27 and again on August 1. The third leaf from the base of the stalk was taken and leaves from three plants constituted the sample for each plot. The leaves were immediately placed

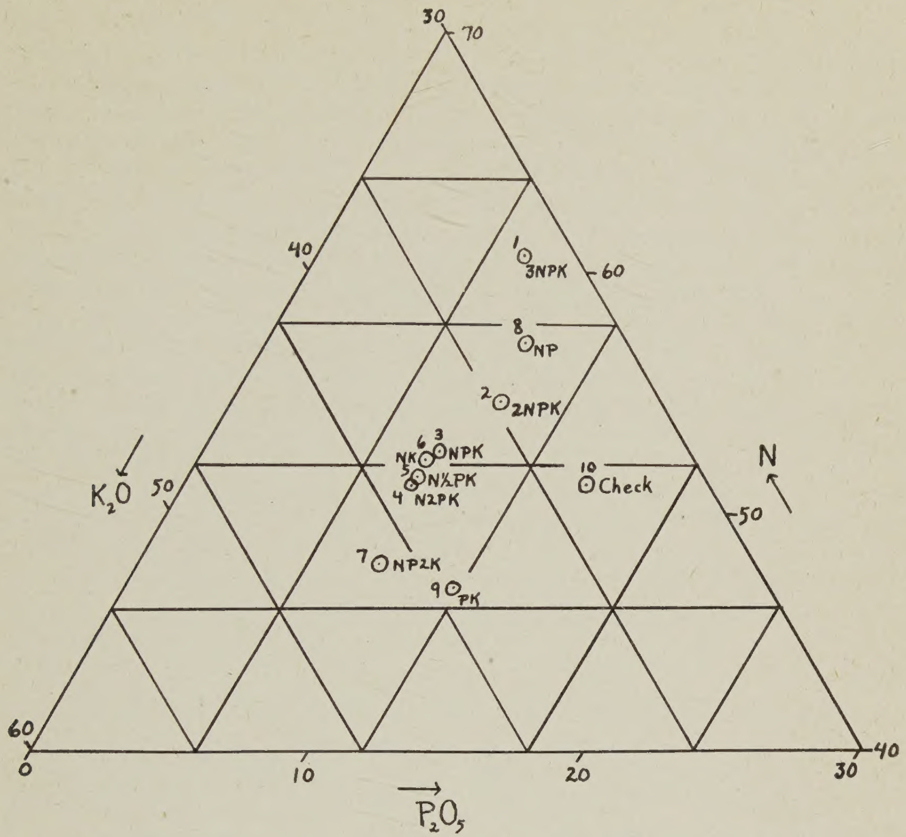


FIGURE 2. Average NPK-Unit Values—Corn, *Area No. 1.* (Numbers refer to order of yields.)

in an oven at 70° C. until dry, then ground in a Wiley laboratory mill to pass a 40-mesh screen. Just before analysis, they were again dried at 70° C. in a vacuum oven to give moisture-free material.

The samples were analysed for nitrogen, phosphorus, potassium, calcium and magnesium. The nitrogen and phosphorus were determined in aliquots of a solution obtained by wet-ashing a sample with $H_2SO_4$ and 30% $H_2O_2$ (4). Nitrogen was measured by nesslerizing, using Koch and McMeekins' solution (4). Phosphorus was determined using a 2.5% solution of ammonium molybdate in 10N $H_2SO_4$, with a 1% solution of $SnCl_2$ in 10% HC1 as reducing agent. The potassium, calcium and magnesium were determined in aliquots of a solution obtained by dry-ashing, treating with acid and removing the acid-insoluble matter (probably mostly silica) which was also determined. The methods for these three elements were those currently used in these laboratories (1). All these results were calculated to a silica-free basis.

## RESULTS WITH CORN PLANTS

In considering the effect of treatment on the composition of the leaves, attention is drawn to the following facts which are apparent from the results as presented in Table 1 and Figure 1.

The nitrogen content of the leaves from the 3NPK treatment was significantly greater than all the others, among which there were no significant differences. The phosphorus content of the leaves from the PK and check treatments was significantly higher than that from all other treatments, including the N2PK treatment which carried the heaviest application of phosphorus. Moreover there were no significant variations in phosphorus content of the leaves from treatments involving increasing phosphorus applications in the presence of nitrogen and potassium, *i.e.*, the NK, N$\frac{1}{2}$PK, NPK, and N2PK treatments. The potassium content of leaves from the check and NP plots was significantly lower than all others. Although the amount of this element in the leaves from the NP treatment was significantly lower than in the leaves from the NPK treatment, there was no significant difference between leaves from the latter treatment and the leaves from the NP2K treatment. In the case of calcium, the lowest amount of CaO was found in leaves from the PK treatment and the highest in leaves from the 3NPK treatment. The CaO content in leaves from the heaviest CaO treatment, *i.e.*, the N2PK treatment, lay between and was significantly different from these two extremes. There were significant differences between blocks and between sampling dates. On certain treatments it was found that interactions of block on treatment, not shown in the tables, were significant for phosphorus, potassium and calcium contents of the leaves. There was also a significant interaction of block on sampling date for CaO content of the leaves.

Thus it is evident that there was no simple and direct response in composition of the corn leaves to the amounts of any of the fertilizer elements supplied. The variability in the composition of the leaves of corn plants grown over a small area, as shown by the block differences and interactions, is also noteworthy.

In consideration of the possible correlations between yield and composition of the leaves, the "intensities of nutrition" and the NPK-units, the following facts apparent from Table 1 and Figures 1 and 2 should be noted.

All fertilizer treatments with the exception of PK gave significant increases over the untreated plots. Records over a period of years have shown that crops have responded to applications of a nitrogenous fertilizer on this area, and in agreement with this, the highest yields were obtained where the highest rates of nitrogen were applied to the soil. The NPK, 2NPK and 3NPK treatments gave yields that were significantly greater than that for the PK treatment; the two highest yields, from the 2NPK and 3NPK treatments, were almost identical. But the nitrogen content of the leaves was significantly increased by only one treatment, the 3NPK. The high nitrogen content of the leaves from this treatment might be interpreted as luxury consumption of the element by the corn plants. The yields for the plots receiving varying amounts of phosphate fertilizer (NK, N$\frac{1}{2}$PK, NPK and N2PK) were close, ranging only from 27.08 to 28.05 lb. However, the phosphorus content of the leaves from these treatments did not vary significantly. The potassium content of the leaves was significantly increased in every case where potash was applied in the fertilizer, but there was no corresponding variation in the yields.

Table 2.—Tomato plants—area No. 1

Mean values for treatments and blocks

(Analytical results on moisture-free and silica-free basis)

| Treatments | % N | % $P_2O_5$ | % $K_2O$ | % CaO | % MgO | *Yield Kg. |
|---|---|---|---|---|---|---|
| Check | 2.91 | 0.61 | 2.70 | 7.06 | 0.79 | 5.56 |
| PK | 3.42 | 0.64 | 2.92 | 8.19 | 0.72 | 6.33 |
| NP | 3.30 | 0.59 | 2.35 | 8.49 | 0.90 | 11.17 |
| NK | 3.51 | 0.51 | 3.72 | 7.50 | 0.81 | 8.51 |
| NPK | 3.56 | 0.55 | 4.03 | 7.80 | 0.74 | 11.01 |
| 2NPK | 3.50 | 0.54 | 3.70 | 8.06 | 0.90 | 13.66 |
| 3NPK | 3.59 | 0.53 | 3.62 | 6.89 | 0.85 | 11.32 |
| N½PK | 3.38 | 0.50 | 3.50 | 8.37 | 0.80 | 9.12 |
| N2PK | 3.16 | 0.54 | 3.16 | 9.25 | 0.83 | 10.80 |
| NP2K | 3.24 | 0.52 | 3.57 | 8.56 | 0.78 | 7.72 |
| Necessary difference (P = 0.05) | — | — | 0.53 | — | — | 2.57 |
| Block 1 | 3.54 | 0.64 | 3.78 | 7.85 | 0.74 | 8.85 |
| 2 | 3.73 | 0.56 | 3.08 | 8.07 | 0.83 | 7.77 |
| 3 | 3.07 | 0.55 | 3.52 | 7.52 | 0.66 | 9.19 |
| 4 | 3.08 | 0.48 | 2.94 | 8.63 | 1.03 | 12.27 |
| Necessary difference (P = 0.05) | 0.34 | — | 0.34 | — | 0.15 | 1.62 |

* The yield data represent the total weight of tomatoes per plot as harvested when ripe.

The differences in yield from treatment to treatment did not follow the changes in the amounts of the various elements found in the leaves, nor in the variations of the "intensity of nutrition" values. The close similarity between the intensity of nutrition and leaf potash content graphs is very striking. The two graphs show some divergence only for the 3NPK treatment, where, as noted above, the nitrogen content of the leaves was significantly increased over that for all other treatments.

In Figure 2, the mean NPK-unit values for each treatment are plotted on trilinear co-ordinates. As an aid in reading this type of diagram, three examples of NPK-unit values, which appear in Figure 2, are given in the table below.

| Treatment | Co-ordinate values for N | $P_2O_5$ | $K_2O$ |
|---|---|---|---|
| 3NPK | 60.7 | 7.4 | 31.9 |
| 2NPK | 54.5 | 9.7 | 35.8 |
| Check | 51 2 | 14.4 | 34.4 |

The yields from seven of the ten treatments were in fair agreement with the points on the diagram. The 2NPK treatment was ranked second in yield (33.07 lb.) but this was almost identical with the highest yield (33.09 lb.). The points for the treatments giving yields ranked third to sixth were all closely clustered on the diagram immediately below that for 2NPK; the yields for these treatments were also very close (27.08 lb. to 28.05 lb.). The NPK-units for the treatments ranked seventh and ninth with respect to yield were plotted somewhat further away from that for

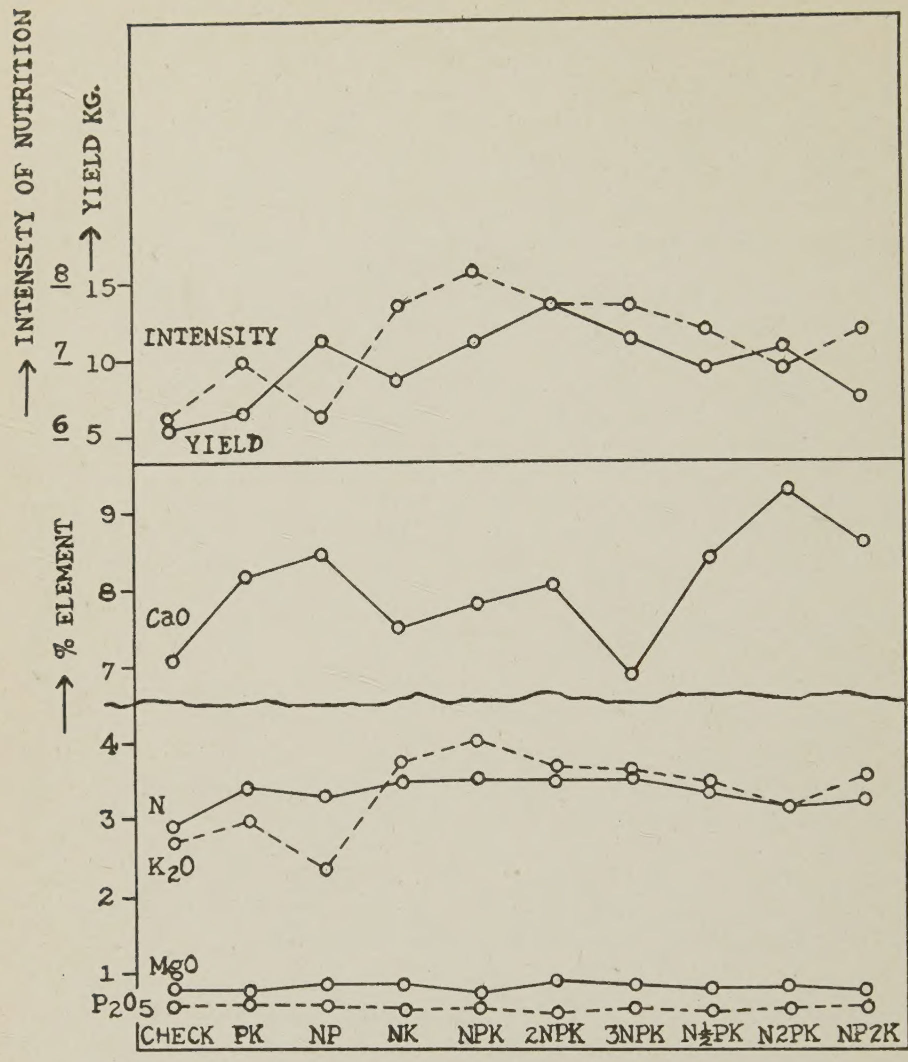


FIGURE 3. Mean per cent Composition, Yield and "Intensity of Nutrition"—Tomatoes, *Area No. 1.*

2NPK. The remaining three NPK-units representing the treatments 3NPK, NP and check whose yields were ranked first, eighth and tenth, respectively, did not fit in with the others.

If some relationship existed between the NPK-unit and the yield, one might expect that the points for the 3NPK and 2NPK treatments would be close together. However, the increased uptake of nitrogen by the leaves from the 3NPK treatment has resulted in the NPK-unit for this treatment being placed considerably higher in the diagram. Similarly, on the basis of yields, one might have expected the other two points from the treatments NP and check to have occurred much lower down in the figure. It was pointed out above that the potassium content of the leaves in these two

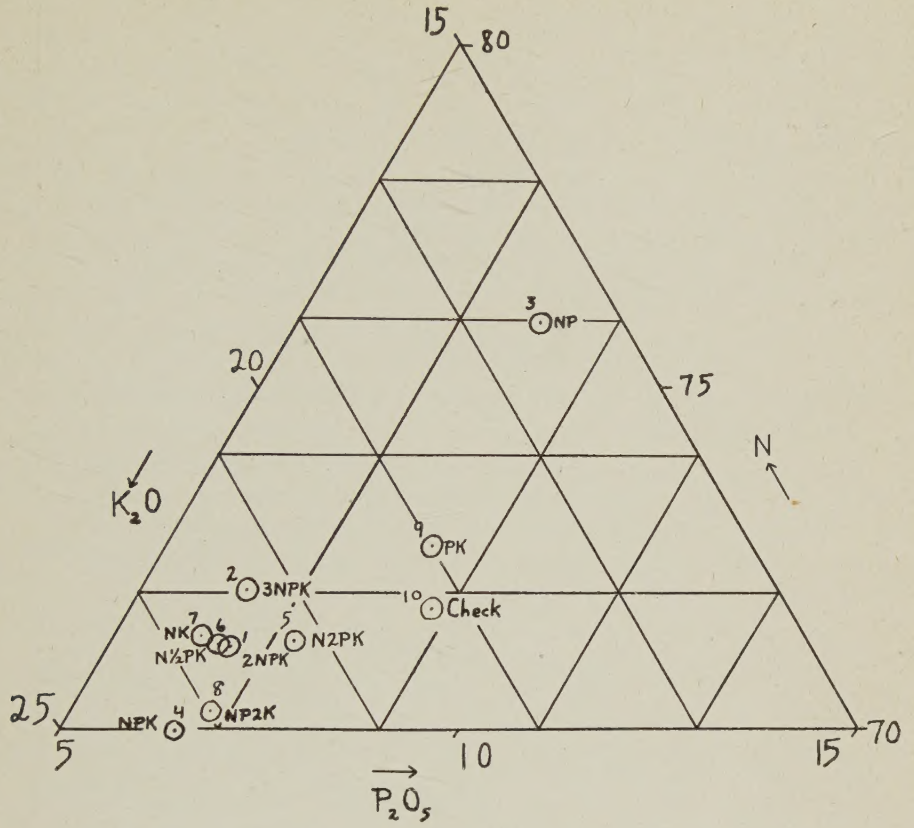


FIGURE 4. Average NPK-Unit Values—Tomatoes, *Area No. 1*. (Numbers refer to order of yields.)

cases was low and, in view of the relatively high content of potassium in relation to nitrogen and phosphorus, it is not surprising that these two points are out of line.

## RESULTS WITH OTHER CROPS

Leaves from the tomato plants on area No. 1 were taken only once during the season, on July 12, the seventh leaf from the base of the stem being selected. They were treated in a manner similar to that used in the case of the corn leaves and were analysed for the same constituents. The results are presented in Table 2 and Figures 3 and 4.

When variations in plant composition, intensity of nutrition and yield for the tomato plants were plotted against fertilizer treatment, as was done in the case of the corn results in Figure 1, it was observed that, here again, the intensity of nutrition curve closely paralleled that of the potassium content of the leaves. It was further noted that, as with the corn crop, the differences in yields of tomatoes from treatment to treatment did not follow the changes in the amounts of the various elements found in the leaves, nor in the variation of the "intensity of nutrition" values. When the NPK-units were plotted on trilinear co-ordinates, there was no

regularity between the distribution of these points on the diagram and the yields of tomatoes obtained. The effect of nitrogenous fertilizers on this area was shown in the tomato yields as in the corn yields. The yields from all treatments containing nitrogen, with the exception of NP2K, were significantly greater than those from the untreated plots.

On area 2, leaves from tomato plants and from oat plants were taken once during the season and treated in the manner outlined above for those from corn and tomatoes on area 1. For the sake of brevity, the details of these results are not presented, but a study of the data so obtained led to conclusions similar to those reached in the previous cases.

## CONCLUSIONS

The results from the foliar diagnoses on all of the plants studied led to the following conclusions:

There was no simple and direct relationship between the compositions of the leaves of these plants and the additions of the elements to the soils, in the fertilizers, nor between the yields and either the intensity of nutrition values or the leaf content of any of the three elements nitrogen, phosphorus or potassium.

When the NPK-units were calculated and plotted on trilinear graph paper, the distribution of the points showed no simple relationship with the yield obtained. While in the case of some treatments, as pointed out in connection with the results for corn presented in Figure 2, there appeared to be some agreement, there was also a sufficient number of exceptions to preclude a positive conclusion being drawn. In most cases, these exceptions appeared to be connected with the variation in leaf potassium and nitrogen due to fertilizer applications. Where these elements were low or high in the leaf, they materially affected the relationship found among the three elements being considered, without affecting the yields in a corresponding manner.

## SUMMARY

A study of the method of foliar diagnosis as proposed by Lagatu and Maumé, and developed by Thomas and Mack, has been carried out.

Leaf samples from corn plants were taken twice in a season and only once from oats and two sets of tomato plants. The yields of all crops were determined.

The dried leaves were analysed for N, P, K, Ca, Mg and acid-insoluble material. The "intensity of nutrition" values (% N + %$P_2O_5$ + %$K_2O$) were calculated and the NPK-units (quantities in the leaf converted to milliequivalents and expressed as percentages of their sum) were plotted on trilinear graph paper.

The nitrogen content of the leaves varied with the plant. It was lowest in the corn leaves ($1\frac{1}{2}$% to 2%), somewhat higher in the tomato leaves (3% to 4%) and highest in the oat leaves ($4\frac{1}{2}$% to 5%). Treatments had little effect on leaf nitrogen except in two cases where a very high rate of application (3N) brought about significant increases.

The phosphorus content of the leaves was always less than 1 per cent and in all cases was unaffected by fertilizer application of phosphorus. However, applications of nitrogen significantly reduced the phosphorus content of the corn leaves.

The potassium content of the leaves showed the greatest variation from treatment to treatment. It was always lowest in those cases (NP and check plots) where no potash was applied to the soil. Variations in potash content were between 3 per cent and 5 per cent and were somewhat lower in the tomato leaves (avg. 3.3% $K_2O$) than in the corn leaves (avg. 4.4% $K_2O$).

The difference in calcium content between the corn and tomato leaves was very pronounced. The corn leaves contained about 1 per cent CaO and the tomato leaves about 8 per cent CaO. There was much less difference in the magnesium content, the tomato leaves averaging 0.81 per cent MgO and the corn leaves 0.54 per cent MgO.

In general, variations in the "intensity of nutrition values" closely paralleled changes in the potassium content of the leaves.

There was no simple and direct relationship between yields and either the "intensity of nutrition" values or the leaf content of nitrogen, phosphorus or potassium.

There was no simple and direct relationship between yields and the location of the NPK-units on trilinear graph paper. When potassium was low or nitrogen was high in the leaf, the relationship among the three elements being considered was materially modified, while the yields were not affected in a corresponding manner.

Under the conditions of this experiment, the use of "intensity of nutrition" values and NPK-units as employed in the method of foliar diagnosis under study was not satisfactory. This appeared to be due to the fact that large variations in leaf potassium and leaf nitrogen were brought about by variations in fertilizer treatment without corresponding effects on crop yields.

## REFERENCES

1. Chemical Methods of Soil Analysis, pp. 43 to 47, incl. Division of Chemistry, Science Service, Department of Agriculture. February 1946.
2. Lagatu, H., and L. Maumé. Ann. Ecole Nat. Agr. Montpellier 20 : 219-281. 1930.
3. Lagatu, H., and L. Maumé. *ibid.* 22 : 50-126. 1932.
4. Lindner, R. C. Plant Physiol. 19 : 77. 1944.
5. Salter, R. M., and J. W. Ames. Plant composition as a guide to the availability of soil nutrients. J. Am. Soc. Agron. 20 : 808-836. 1928.
6. Thomas, W. Foliar diagnosis: Principles and practice. Plant Physiol. 12 : 571-599. 1937.
7. Thomas, W., and W. B. Mack. Foliar diagnosis in relation to development and fertilizer treatment of potatoes. J. Agr. Res. 57 : 397-414. 1938.
8. Thomas, W. Foliar diagnosis. Its relation to the optimum nutrition of the potato. Plant Physiol. 13 : 677-694. 1938.
9. Thomas, W., and W. B. Mack. Foliar diagnosis. The influence of the soil on the action of fertilizers. *ibid.* 14 : 75-92. 1939.
10. Thomas, W., and W. B. Mack. Foliar diagnosis. Physiological balance between the bases lime, magnesia and potash. Plant Physiol. 14 : 699-715. 1939.

11. Thomas, W., and W. B. Mack. The foliar diagnosis of *Zea Mays* subjected to differential fertilizer treatment. J. Agr. Res. 58 : 477-491. 1939.
12. Thomas, W., and W. B. Mack. A foliar diagnosis study of the influence of calcium from two sources, lime and superphosphate. *ibid.* 58 : 685-693. 1939.
13. Thomas, W., and W. B. Mack. A foliar diagnosis study of the effect of three nitrogen carriers on the nutrition of *Zea Mays*. *ibid.* 59 : 303-313. 1939.
14. Thomas, W., and W. B. Mack. Foliar diagnosis of differentially fertilized greenhouse tomatoes with and without manure. *ibid.* 60 : 811-832. 1940.
15. Thomas, W., and W. B. Mack. A foliar diagnosis study of climatic influences on the nutrition of spring and fall grown tomatoes. Plant physiol. 16 : 117-144. 1941.
16. Thomas, W., and W. B. Mack. Foliar diagnosis in relation to soil heterogeneity. Soil Sci. 52 : 455-460. 1941.
17. Thomas, W., and W. B. Mack. Foliar diagnosis in relation to plant nutrition under different conditions of weather and soil reaction. Soil Sci. 56 : 197-212. 1943.
18. Thomas, W., W. B. Mack and E. M. Rahn. Foliar diagnosis and plant nutrition in fertilizer placement experiments. J. Am. Soc. Agron. 36 : 889-902. 1944.

# SPRAYING AND DUSTING TURNIPS TO PREVENT WATER CORE, A DISORDER CAUSED BY BORON DEFICIENCY[1]

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## INTRODUCTION

Water Core and Brown Heart are two names ascribed to a physiological disorder of turnips (rutabagas) caused by boron deficiency. The initial symptoms are expressed as a water-soaked appearance within the turnip root, while in more advanced stages the affected tissue turns brown; hence the two names. In Western Ontario the former condition usually obtains, and for that reason the name "Water Core" is commonly used by the growers.

An earlier publication (1) gave the initial recommendations for foliage spraying of turnips (rutabagas) with a borax preparation to prevent water-core development. Since then the spray technique has been improved and simplified, and a borax dust mixture has proved to be effective.

Spraying or dusting for the prevention of water core is now being used generally in the turnip areas of Southwestern Ontario. This is especially true in the high-lime soil areas where soil applications of borax have failed to give results. Three owners of spraying and dusting machines who did custom work co-operated to the extent that much useful information was obtained from large scale operations. Special attention was given to the relative efficiency of spraying versus dusting, the range of turnip-size during which water core can be prevented by foliage applications of borax, and the influence of the weather conditions prevailing at the time of application. This is a report of the experimental findings of 1945 and 1946, and the present recommendations for spraying and for dusting.

## INVESTIGATIONS

### *Materials and Methods*

Records were obtained on the custom work done by a sprayer during 1945 and 1946, and two dusters during 1946. The sprayer was a "Massey-Harris" 4-row, 12 nozzle, traction-driven unit developing a pressure of approximately 125 lb. The two "Friend" dusters were 4-row power-driven units with two outlets per row; one was equipped with an apron, while the other was not. All three units were used in the Ayr, Bright, Drumbo and Innerkip areas of Ontario.

The spray mixture contained 12 lb. of powdered borax (finer than table salt), 3 lb. of bentonite clay and 1 pint (20 fluid oz.) of liquid Orthex to 40 gal. of water. The dust mixture contained very fine borax (300 mesh) and *No. 209* "Celite" mixed in equal proportions by weight. It was recommended that the turnips be sprayed or dusted when the root diameter was between 1 and $1\frac{1}{2}$ in., using 40 to 50 gal. of the spray mixture per acre or 40 to 50 lbs. of the dust preparation per acre.

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[2] Professor of Botany.
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Table 1.—The control of water core of turnips obtained by spraying and by dusting

| Unit | Year | Total numbers of fields | Total acreages | % of treated fields: With no water core | % of treated fields: Commercially free of water core | % of treated fields: With severe water core | Fields with checks: Number | Fields with checks: % Water core in checks |
|---|---|---|---|---|---|---|---|---|
| Sprayer | 1945 | 21 | 78 | 67 | 33 | 0 | 1 | 50 |
| Sprayer | 1946 | 27 | 75 | 74 | 26 | 0 | 10 | 30 to 100 |
| Duster — With apron | 1946 | 33 | 139 | 67 | 33 | 0 | 11 | 20 to 90 |
| Duster — Without apron | 1946 | 18 | 56 | 53 | 47 | 0 | 6 | 20 to 75 |
| | Totals | 99 | 348 | | | | | |

At the time of spray or dust application records were made of turnip size, weather conditions and, in the case of dusting, whether the leaves were wet or dry. In 28 fields it was possible to have check areas of adequate size. The main source of data on the effectiveness of spraying and dusting was derived from a questionnaire sent to individual growers after the turnips were harvested, but about 25 per cent of the fields were inspected by the authors at harvest time.

### *Observations and Conclusions*

Information concerning the control of water core obtained by spraying and by dusting is given in Table 1. All the fields were commercially free of water core and, with the exception of those on which a duster was used without an apron, at least two-thirds were entirely free of water core. Scattered water-core turnips can be expected owing to insufficient coverage, particularly at the ends of the rows. Furthermore, occasional plants may not be at the optimum stage of development at the time of spray or dust application. The numbers of fields in which it was possible to arrange for check areas are also given in Table 1. The incidence of water core in these check areas varied from 20 per cent to 100 per cent. Water core was especially severe in 1946, when many untreated fields were condemned for shipping purposes because of water core.

On the basis of observed performance, dusters should be equipped with aprons. With an apron there is less wind drift of the dust, a better coverage of the undersides of the leaves is obtained and, as indicated in Table 1, a higher percentage of fields entirely free of water core can be expected. The records indicated that the efficiency of the dust is not affected by the presence or absence of moisture on the leaves at the time of application. The dusters operated throughout the day except during very high winds or while it was raining. In no instance was dusting repeated if a rain followed immediately after application.

Most of the turnips were sprayed or dusted between the middle of July and the middle of August. Meteorological records were kept at the time of application according to the following: temperature—hot, moderate, cool; wind—none, light breeze, windy; sky—sunny, cloudy. Variations

FIGURE 1. Dusting turnips with the borax-celite mixture to prevent water-core development.

in the foregoing apparently had no effect on the control of water core obtained. In no instance was foliage burning observed after spraying or dusting.

Previous work showed that application of the spray or dust should be made when the root of the turnip is between 1 and $1\frac{1}{2}$ in. in diameter, because if the plant is less mature than indicated above, there is insufficient foliage to hold an adequate amount of the borax spray or dust; if more mature, water core may develop before sufficient boron has been absorbed. The 1945 and 1946 applications were made, in a few fields, when the roots were 2 in. or more in diameter. In the majority of these instances occasional water-core turnips were found at harvest time.

On the basis of present evidence, spraying and dusting are equally effective. The cost of ingredients for spraying is less than that for dusting but the labour involved in the spray application is greater. The cost to the grower for custom spraying or dusting varies from $4.00 to $5.00 per acre depending upon the assistance given during operations. Application by custom units has proved to be the most satisfactory and efficient method.

Foliage application of borax is now being generally accepted as the most satisfactory method to prevent water-core development in many turnip areas of south-western Ontario. Within the area upon which the records used in this publication are based, there was one custom sprayer in 1945 which sprayed 78 acres. In 1946 there was one sprayer and two dusters which covered 270 acres. In 1947, at the time of writing, there are twelve units, mostly dusters, and it is anticipated that more than 2000 acres will be covered. Several other spray and dust units are in operation elsewhere in the turnip areas of Ontario. In so far as could be ascertained, the results being obtained are similar to those described herein.

## DIRECTIONS FOR FOLIAGE AND SOIL APPLICATIONS OF BORAX TO PREVENT WATER CORE OF TURNIPS

*Spray*

The recommended spray ingredients are 12 lb. of powdered borax, 3 lb. of bentonite clay and 1 pint (20 fluid oz.) of Orthex in 40 imperial gal. of water. The borax should be of sufficient fineness (finer than table salt) to pass through the spray nozzles as a suspension. Whether or not the bentonite clay is necessary, when Orthex is used as a spreader and sticker, may be open to question, but it gives an indication of the coverage being obtained. The borax and clay should be mixed together, while dry, prior to adding to the water. The prepared mixture is now being sold by The Niagara Brand Spray Co., Burlington, Ontario.

A power sprayer, either traction or motor driven, that will give at least 125 lb. pressure, is preferred. An agitator in the tank is necessary. Three nozzles per row should be used with the centre nozzle directed down on the leaves and the two side nozzles set as low as possible and directed towards each other. Forty to 50 gal. of spray should be applied per acre when the diameter of the turnip root is between 1 and $1\frac{1}{2}$ in.

*Dust*

The recommended dust ingredients are very finely powdered borax (300 mesh) and "Celite" (*No. 209*) mixed in equal proportions by weight. The mixture is now being prepared and sold by The Bartlett Spray Works, Beamsville, Ontario; The Niagara Brand Spray Co., Burlington, Ontario; and Canadian Industries Ltd., Toronto, Ontario.

A power duster with two outlets per row and equipped with an apron is preferred. The results obtained, so far, indicate that dust application may be made any time of the day except while raining or during very high winds. Forty to 50 lb. of the dust mixture should be applied per acre when the diameter of the root is between 1 and $1\frac{1}{2}$ in.

*Soil Applications of Borax*

Specially prepared borated fertilizers are available for use in turnip districts where soil applications of borax give satisfactory results.

There are districts where the routine method of soil application of borax fails to give satisfactory results and yet equipment for foliage application is not available. In such instances it is suggested that the borax be applied after thinning rather than before seeding, at the rate of 20 to 30 lb. per acre. Granulated borax may be applied as a side dressing or else broadcast with a hand, cyclone grass-seeder. The delayed application of the borax provides a better opportunity for boron absorption prior to soil fixation.

## SUMMARY

Foliage application of borax to prevent water core (brown heart) development in turnips (rutabagas) has given very satisfactory results on a large acreage basis in Western Ontario. The borax may be applied as a spray or as a dust. The spray ingredients are 12 lb. of borax of sufficient fineness to pass through spray nozzles as a suspension, 3 lb. of bentonite clay and 1 pint (20 fluid oz.) of Orthex in 40 imperial gal. of water. The borax and clay should be mixed together while dry prior to adding to the water. The dust ingredients are finely powdered borax (300 mesh) and *No. 209* Celite mixed in equal proportions by weight. An application of 40 to 50 gal. of the spray, or 40 to 50 lb. of the dust, per acre should be made when the diameter of the turnip root is between 1 and $1\frac{1}{2}$ in. Custom spraying or dusting with powered equipment is recommended. In areas where spray or dust equipment is not available and where soil fixation of boron is rapid, it is suggested that granulated borax be applied as a side-dressing or broadcast with a hand, cyclone grass-seeder at the rate of 20 to 30 lb. per acre after the seedling plants are thinned.

## REFERENCE

1. MacLachlan, J. D. Control of water core of turnips by spraying with borax. Scientific Agriculture 24 : 327-331. 1944.

# FEEDING UREA TO DAIRY COWS WITH SPECIAL REFERENCE TO THE PALATABILITY OF FEED MIXTURES CONTAINING UREA[1]

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Armsby (1) in 1911 advanced the theory that micro-organisms present in the paunch of the ruminant might possess the ability to synthesize protein from non-protein nitrogen. Work done since that date fully substantiated this theory. Once this concept of non-protein nitrogen utilization by ruminants was established investigators began experiments to determine the extent of this utilization and to test the efficiency of various non-protein nitrogenous compounds as substitutes for the protein of linseed meal, blood meal, etc.

Impending scarcity of animal and plant proteins at the onset of World War II intensified this research and investigators, working mainly with urea, published several reports (2, 3, 4, 5, 6, 9, 10, 12 and 13) on the different phases of the subject. One general conclusion reached by these various workers was that urea, substituted for linseed meal on an equal nitrogen basis, was as effective for maintenance, growth and production as linseed meal.

In the fall of 1943 experiments to determine the value of urea under Alberta feeding conditions were initiated at the University of Alberta (7). The experiments, which extended through the winters of 1943-45, were financed in part by a grant from the Consolidated Mining and Smelting Company of Canada, Limited.

For the first experiment, 1943-44, four pairs of cows were chosen. One cow of each pair received a linseed meal grain mixture, and the other cow of each pair was fed a grain mixture in which all of the linseed meal and a small portion of the wheat bran was replaced by $2\frac{1}{2}$ per cent of urea. Enough of the carbonaceous feeds were added to this mixture to give it practically the same T.D.N. content as the linseed meal mixture. Table 1 gives the composition of these two grain mixtures.

[1] Contribution from the Department of Animal Science, University of Alberta, Edmonton, with financial assistance from the Consolidated Mining and Smelting Company of Canada, Limited. Part of a thesis for a Master of Science degree.
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Table 1.—Composition of urea and linseed meal grain mixtures

| | Urea | Linseed meal |
|---|---|---|
| | lb. | lb. |
| Wheat bran | 390 | 400 |
| Oats | 1249 | 800 |
| Barley | 312 | 200 |
| Urea | 49 | — |
| Linseed meal | — | 600 |
| | 2000 | 2000 |
| Crude protein equivalent (N × 6.25) | 18.0% | 17.2% |

Roughage requirements of all cows were met by oat-silage and mixed timothy-alfalfa hay. All cows were fed according to Morrison's feeding standards (11), using weekly data on production and body weights.

Two pairs of these cows were fed the experimental rations for 14 consecutive weeks while the other two pairs received theirs for 9 and 7 weeks, respectively.

Data obtained during this trial indicated that the urea ration was not completely palatable to dairy cows. While all cows fed the urea mixture consumed it more slowly than they had consumed the linseed meal mix, certain individual cows demonstrated more dislike than others. One cow on the urea ration gradually went off feed and was removed from the experiment after she had lost considerable weight.

Data obtained in this first experiment were considered insufficient to provide a conclusive answer to the effect of substituting urea for linseed meal since there was some question as to the palatability of mixtures containing urea. Consequently, a similar experiment was outlined for the winter of 1944-45.

Fourteen cows in all were chosen for this experiment and they were allocated to three different rations in such a way that direct comparisons were possible between each of the following grain mixtures:

1. Urea (2 per cent)
2. Urea (1 per cent) and linseed meal
3. Linseed meal.

Table 2.—Composition of the grain mixtures fed

| | Urea mixture | Urea-linseed meal mixture | Linseed meal mixture |
|---|---|---|---|
| | lb. | lb. | lb. |
| Wheat bran | 400 | 400 | 400 |
| Oats | 1160 | 1030 | 900 |
| Barley | 400 | 400 | 400 |
| Urea | 40 | 20 | — |
| Linseed meal | — | 150 | 300 |
| | 2000 | 2000 | 2000 |
| Crude protein equivalent ($N \times 6.25$) | 18.1% | 16.4% | 14.8% |
| T. D. N. | 71.4% | 72.6% | 73.9% |

The roughage requirements of these cows were met by green oat silage and a mixed timothy oat hay.

Once again, however, the problem of palatability appeared. Cows receiving a grain mixture containing urea always consumed it more slowly than they did a grain mixture containing bran and linseed meal as the protein supplements. Three cows, two Jerseys and one Holstein, refused to eat enough of the grain mixture to meet body requirements and had to be withdrawn from the experiment.

A thorough review of literature available up to this time dealing with the feeding of urea to dairy cattle revealed no direct mention of unpalatability and further experiments were deemed essential to study this problem.

## PALATABILITY STUDIES

### Experiments 1945-1946

In the fall of 1945 the University undertook experimentation designed solely to investigate the palatability problem. Work during this period was divided into two sections:

I. The possibility of accustoming animals to the taste of urea by its gradual inclusion in their concentrate mixture.

II. The effect of including certain feeds in the ration to disguise the taste of urea.

*SECTION I*

*Plan of Experiment*

Three groups of cows were chosen for this part of the experiment. Cows of lot 1 were abruptly changed from a linseed meal mixture to a mixture containing 2 per cent urea. The other two groups received gradually increased amounts of urea in such a way that cows of lot 2 received the full 2 per cent urea mixture at the end of three weeks and cows of lot 3 received it at the end of five weeks.

Table 3 indicates the rate at which urea was included in the rations of the 3 lots.

TABLE 3.—RATE AT WHICH UREA WAS SUBSTITUTED FOR THE LINSEED MEAL OF THE CONCENTRATE MIXTURE IN TERMS OF THE PERCENTAGE OF UREA ADDED TO THE RATION

| | Lot 1 | Lot 2 | Lot 3 |
|---|---|---|---|
| Preliminary weeks | No urea | No urea | No urea |
| 1st experimental week | 2.0% | 0.33% | 0.33% |
| 2nd experimental week | 2.0% | 0.80% | 0.66% |
| 3rd experimental week | 2.0% | 1.60% | 0.99% |
| 4th experimental week | 2.0% | 2.00% | 1.33% |
| 5th experimental week | 2.0% | 2.00% | 1.66% |
| 6th and succeeding weeks | 2.0% | 2.00% | 2.00% |

The remainder of the cows in the herd were fed the usual linseed meal mixture and served, in a general way, to check the frequency of digestive and palatability disturbances.

The urea mixture and the linseed meal mixture were constituted as shown in Table 4. These mixtures were combined in proper proportions to obtain mixtures containing less than 2 per cent urea.

The urea (du Pont's "262" feed compound) was passed through a 1/16-in. screen before mixing to remove the small, hard lumps that were invariably present. To ensure thorough mixing all concentrate mixtures were mixed for one-half hour in a mechanical vertical-auger type mixer.

Roughage consisted of alfalfa, green oat hay and green oat silage. The cows were fed in accordance with the Morrison standards using weekly data of body weight and production.

TABLE 4.—COMPOSITION OF THE CONCENTRATE MIXTURES FED

| | Urea | Linseed meal |
|---|---|---|
| | lb. | lb. |
| Barley | 400 | 400 |
| Oats | 1160 | 900 |
| Wheat bran | 400 | 400 |
| Linseed meal | — | 300 |
| du Pont's "262" urea | 40 | — |
| | 2000 | 2000 |
| Crude protein equivalent (N × 6.25) | 19.1% | 17.5% |

Ten Holsteins and six Jerseys were fed for periods varying from 3 to 22 weeks in length. These cows were chosen so as to represent all stages of lactation and, when placed on the experiment, received grain allowances of 6 pounds to 15 pounds daily.

*Results*

At no time did any cow on urea show the same relish for her grain allowance as did cows fed the standard linseed meal mixture, since they were slow to consume their allowance and rarely licked up the last traces of grain in their manger. This had, however, no apparent adverse effect on body weight or milk production.

More aversion to urea was demonstrated by cows that were gradually brought to a 2 per cent urea mixture in three and six weeks respectively than by the cows that were suddenly switched to the 2 per cent urea mixture. The explanation for this was not apparent from the data.

However, in addition to this rather passive aversion, there were five cows that developed an active dislike for the urea. These cows consumed their grain allowance more or less normally during the first part of the experiment and seemed to become accustomed to the urea. However, after about twelve weeks, they started to refuse part or all of the grain allowance and reduced milk yields and a decrease in live weight naturally resulted. It was found impossible to bring these cows back to full grain consumption on the urea ration but when they were offered the linseed meal mixture they consumed it with great eagerness.

The results proved that gradually increasing the urea allowance over a three- or a six-week period did not accustom the cows to the taste of urea as all cows gave evidence that they disliked the urea mixture.

## *SECTION II*

*Plan of Experiment*

When cows developed a definite dislike for the urea mixture fed in the first part of this experiment their rations were altered to determine whether (*a*) a urea-corn grain mixture, (*b*) the addition of molasses, would disguise the taste of urea and render rations containing this compound more palatable.

The urea grain mixture containing corn was formulated as recommended by the manufacturer of the "262" feed compound while 10 per cent of "Betalasses", a by-product of the sugar refinery at Raymond,

Alberta, was added to the 2 per cent urea grain mixture to compound the molasses mixture. To ensure a uniform incorporation of this molasses it was always premixed with oats before being placed in the mechanical mixer. The compositions of the corn and molasses mixtures are shown in Table 5.

TABLE 5.—COMPOSITION OF THE GRAIN MIXTURES CONTAINING CORN OR MOLASSES

| | Corn mixture | Molasses mixture |
|---|---|---|
| | lb. | lb. |
| Barley | 500 | 400 |
| Corn | 500 | — |
| Oats | 500 | 1160 |
| Wheat middlings | 200 | — |
| Wheat bran | 214 | 400 |
| "262" urea | 43 | 40 |
| "Betalasses" | — | 200 |
| | 1957 | 2200 |
| Crude protein equivalent ($N \times 6.25$) | 19.4% | 18.5% |

*Results*

(*a*) The urea-corn mixture was offered to only two cows. While both consumed it with somewhat more relish than they had the previous urea mixture, neither one would eat enough to meet body and production requirements. During the second week one cow refused to eat any of the urea-corn mixture during a 24-hour period. The other cow also failed to consume her daily allowance after three weeks of feeding the urea-corn mixture. While only two cows were used, they gave sufficient evidence that the addition of corn did not wholly disguise the taste of urea.

(*b*) Molasses was added to the urea mixture fed to two cows that showed a definite dislike for urea. The urea-molasses mixture proved exceptionally palatable, and for the first time in the experiment cows fed a urea mixture showed a keen appetite for their grain. They received this urea-molasses mixture for four weeks, during which time they consumed their full allowance without hesitation. The level of urea in the grain mixture for these two cows was then increased from 2 per cent to 3 per cent. During the five weeks they were under observation on this increased urea allowance they failed to show even the slightest dislike for the urea-molasses mixture.

*Summary*

1. Urea, when added to mixtures of feeds commonly used in dairy rations, caused the mixture to be unpalatable and as a result some animals refused to consume their required minimum daily allowance.

2. Gradual inclusion of urea in the grain mixture did not accustom the cows to the taste of this compound.

3. The inclusion of corn in the urea mixture made it somewhat more palatable, but this method of feeding urea did not seem applicable in western Canada when the availability and cost of corn were taken into consideration.

4. The addition of molasses (Betalasses) appeared to improve the palatability and promoted increased consumption of a concentrate mixture containing either 2 or 3 per cent of urea.

*Conclusions*

This experiment confirmed the unpalatable nature of urea and demonstrated, in a limited way, how urea might be successfully fed. However, several problems related to palatability of urea still remained unsolved.

One problem was to determine the minimum amount of molasses required to ensure palatability of grain mixtures containing various amounts of urea. A second problem was to investigate the basic cause for the unpalatable nature of urea and to establish whether continued feeding of urea might cause any physiological disturbance.

**Experiments 1946-1947**

Results obtained in experiments at the University of Alberta consistently demonstrated that urea-containing grain mixtures were unpalatable to dairy cows. Since these results seemed to be in direct opposition to results that had been reported by other experimenters in the field it was felt that correspondence with these experiment stations and with the feed companies that include urea in their commercial mixes might provide valuable information regarding palatability. Accordingly, two form letters were prepared. One, sent to experiment stations at Utah, Cornell, Illinois and Wisconsin and briefly reporting results of experiments at the University of Alberta, requested information that could help to explain the divergency of results obtained. The other letter, sent to commercial feed companies, enquired about their experiences with palatability, the feeds used in compounding their urea mixtures, and other factors that might have a bearing on the problem.

Replies from the Illinois and Cornell stations indicated a similar palatability problem. At Illinois the most satisfactory method found for feeding urea was to dissolve it in corn syrup or molasses. Authorities at the other stations suggested in general that the amount of urea included in the ration may be a factor in determining its palatability and that 1 per cent to 2 per cent urea in the mixture may be the upper limits for satisfactory use.

Replies from the various feed companies also indicated that palatability of the ration was an important factor if the level of urea was too high. One company stated that it had received reports of unpalatability of a mixed feed containing 1 per cent by weight of urea. It was the general opinion that molasses included in the concentrate mixtures accounted for some degree of palatability.

Based on this information and on the results obtained in the experiments at the University further studies were planned to investigate:

I. Use of molasses in urea rations.

II. Palatability of rations containing small amounts of urea.

III. Use of a cobalt supplement.

These studies were commenced in the fall of 1946 with the financial assistance of the Consolidated Mining and Smelting Company of Canada, Limited.

## SECTION I

*Plan of Experiment*

This study was planned to investigate the amount of molasses required to ensure the palatability of a concentrate mixture containing the maximum amount of urea that might be fed*. Consequently the grain mixtures prepared for this experiment contained 3 per cent of urea.

Three lots of cows were chosen. Both Jerseys and Holsteins were included in each lot to determine whether there was any breed difference in the response to molasses supplements.

Since the problem was one of palatability and not of production it was not necessary to select the cows on the basis of age, milk production or fat production. However, an attempt was made to choose cows near the beginning of lactation to ensure feeding periods of reasonable length.

A concentrate mixture containing 3 per cent urea was prepared and molasses added to portions of it to formulate mixtures containing 0 per cent, 3 per cent, 5 per cent and 10 per cent molasses. Table 6 shows the composition of these mixtures. The 10 per cent molasses mixture was to be fed only to those cows that refused the other mixtures.

Table 6.—Composition of the concentrate mixtures

| | Lot 1, 0% molasses | Lot 2, 3% molasses | Lot 3, 5% molasses | 10% Molasses |
|---|---|---|---|---|
| | lb. | lb. | lb. | lb. |
| Barley | 540 | 540 | 540 | 540 |
| Oats | 1200 | 1200 | 1200 | 1200 |
| Bran | 200 | 200 | 200 | 200 |
| "262" urea | 60 | 60 | 60 | 60 |
| Betalasses | — | 60 | 100 | 200 |
| | 2009 | 2060 | 2100 | 2200 |
| Crude protein equivalent (N × 6.25) | 20.26% | 19.90% | 19.66% | 19.12% |
| T. D. N. | 71.24% | 70.89% | 70.65% | 70.11% |

The cows were supplied with as much hay and green oat silage as they would readily consume. The hay, of excellent quality, consisted of one-half alfalfa and one-half timothy. Silage was also of good quality. Salt, bonemeal and water were fed *ad libitum*.

The cows selected for this feeding trial received grain allowances varying from 5 pounds to 11 pounds daily at the start of the experiment. They were fed in accordance with their requirements as recommended by Morrison.

The allocation of cows to these experimental rations, their daily grain allowances at the start of the experiment, and the general results obtained appear in the appendix.

* The Association of American Feed Control Officials Resolution No. 20 adopted in 1941 and amended in 1944 reads, in part, ". . . . Urea is to be used only in such limited quantities as to insure that the total amount present does not exceed 3% of the total grain ration."

*Results and Conclusions*

Results obtained did not indicate that either 3 per cent or 5 per cent of molasses was effective in improving the palatability of a 3 per cent urea mixture and even the inclusion of 10 per cent of molasses did not ensure that a 3 per cent urea mixture would be palatable to all cows.

However, the results were confused by the existence of a definite breed difference in response to the urea-molasses rations. Six of the seven Jerseys fed in the experiment demonstrated a more or less marked dislike for the urea mixtures while only one of the six Holsteins showed a similar response.

Another confusing factor was the extreme individuality of the cows within a breed. This seemed to be the most important factor in determining the response that was given a concentrate mixture containing urea.

One additional observation made during the course of this experiment was that many instances of grain refusal were overcome by mixing silage with the grain at feeding time. From this it seems reasonable to assume that the silage partially disguised the taste of the urea.

This experiment does not indicate what influence 3 per cent or 5 per cent of molasses might have on the palatability of grain mixtures containing less than 3 per cent of urea and further study on this problem is warranted.

## *SECTION II*

*Plan of Experiment*

This experiment was planned to investigate the palatability of grain mixtures containing 0.5 per cent and 1 per cent of urea.

Nine cows, most of them in an early stage of lactation, were selected. Lot 1, consisting of 5 Holsteins, was assigned to the 1.0 per cent urea mixture while lot 2, with 2 Jerseys and 2 Holsteins, was assigned to the 0.5 per cent urea mixture. Their grain allowances at the start of the experiment varied from 8 pounds to 13 pounds daily and grain was fed in accordance with their requirements as recommended by Morrison.

Table 7 shows the composition of the two urea-grain mixtures. The linseed meal mixture fed to the cows in the herd not on experiment is included for comparison. These concentrate mixtures were prepared in the same manner as those mixtures described in the previous section.

Roughages fed were the same as those previously described and salt, bone meal and water were fed *ad libitum.*

*Results and Conclusions*

The results obtained from this part of the experiment again demonstrated the importance of individuality and breed of the cow in determining the response to rations containing urea, *i.e.* the two Jerseys showed dislike for the 0.5 per cent urea mixture while four Holsteins ate the 1.0 per cent urea mixture for 12 weeks with no indication of distaste. However, the fifth Holstein refused the 1.0 per cent urea mixture the first day so was transferred to lot 2.

Table 7.—Composition of the concentrate mixtures

| | Lot 1, 1% urea | Lot 2, 0.5% urea | Linseed meal |
|---|---|---|---|
| | lb. | lb. | lb. |
| Barley | 300 | — | — |
| Oats | 600 | 745 | 800 |
| Bran | 100 | 200 | 200 |
| Linseed meal | — | 50 | 100 |
| "262" urea | 10 | 5 | — |
| | 1010 | 1000 | 1100 |
| Crude protein equivalent (N × 6.25) | 15.36% | 16.20% | 15.74% |
| T. D. N. | 72.87% | 71.34% | 71.96% |

While the 0.5 per cent urea mixture was not palatable to all cows it was noted that though some cows that refused to eat the 1.0 per cent urea mixture would eat the 0.5 per cent urea mixture, the reverse situation never occurred.

However, further studies on the palatability of the 0.5 per cent urea mixture are essential since additional data are required to establish:

(1) The proportion of cows that will refuse to eat grain mixtures containing this amount of urea, and the amount of urea that such cows will tolerate in their concentrate mixture.

(2) The amount of molasses required to ensure the palatability of a 0.5 per cent urea mixture to such cows.

## *SECTION III*

### *Cobalt Supplementation*

During the urea-feeding experiments of 1945-1946 it was noted that 5 cows ate the urea-grain mixture for about 12 weeks before manifesting marked dislike for it. This reaction suggested that continued feeding of urea may have in some way upset either the physiology of the cow or the physiology of rumen digestion. To investigate these possibilities urine samples were collected from these cows and analysed for pH and total nitrogen content. The pH of all samples was found to be within the normal range but the total nitrogen content was above the normal level. This increase could, however, be readily interpreted as a result of the decline in milk production that accompanied the period off feed. It was thus impossible to give any definite explanation of this delayed reaction to urea feeding.

In the 1946-1947 experiment a similar response was obtained. Two cows, No. 6 and No. 11, after consuming their 3 per cent urea rations for about 13 weeks, suddenly went off feed. Here again no explanation was apparent.

A review was subsequently made of literature pertaining to dietary factors known to be implicated in anorexia of ruminants. One of the factors which has been studied is cobalt and certain authorities (8) suggest that its relation to anorexia of ruminants is due to its influence on the organisms of the rumen.

To investigate what influence dietary cobalt might have on the refusal of urea-grain mixtures, cobalt chloride was fed at the rate of about 0.05 gram daily to the two cows previously mentioned (No. 6 and No. 11). At the end of one week they had returned to full feed and the cobalt supplementation was discontinued. From this time until the end of the experiment they remained on full feed and showed no further dislike for the ration.

After this favorable response to cobalt three other cows (Nos. 10, 19 and 20) that had shown dislike for urea rations were fed about 0.05 gram of cobalt chloride daily for 8 days. Reactions to urea rations following this treatment were varied. Cow No. 10, on the linseed meal mixture, refused the 0.5 per cent urea mixture entirely. Cow No. 19, on the 0.5 per cent urea mixture, showed more liking for this ration but refused to eat a mixture containing 1 per cent urea. The third cow (No. 20) had previously refused the 0.5 per cent urea mixture entirely. However, when offered the same mixture following the feeding of cobalt, she ate it for three days before beginning to show dislike.

These limited data appear to indicate that dislike for a urea-grain mixture may, in some cases, be alleviated by the addition of a small amount of cobalt to the ration.

*Conclusions*

Owing to the limited number of cows available for this experiment definite conclusions are impossible but the results obtained suggest that further experimentation is warranted to establish what effect the continued feeding of these urea rations with or without cobalt may have on the bacterial flora of the rumen.

## GENERAL DISCUSSION

Evidence gathered through two years of experimentation with urea indicates that taste of urea is not, *per se*, the factor determining the palatability of a urea mixture. On the contrary, the response accorded such mixtures is the response that might be expected toward a ration which, while satisfactory to the taste, causes certain reactions during digestion that may subsequently cause the cow to avoid it instinctively.

One explanation of the unpalatable nature of certain urea rations may be that they have a deleterious effect on the bacterial flora of the rumen. There is some slight evidence to support this explanation since Weinstein and McDonald (18) recently demonstrated a bacteriostatic effect of urea. In their "in vitro" experiments the level of urea required to inhibit growth varied from 3 per cent to 12 per cent of the media and depended on the species of bacteria and the type of basal media employed. This level of urea would not be attained in the rumen through the feeding of a 3 per cent urea ration but it is possible that under the conditions prevalent in the rumen a lower level of urea may have a bacteriostatic effect. Possibly certain species of bacteria in the rumen are more susceptible to this bacteriostatic action than are those species tested in the study mentioned above.

If urea in the ration does inhibit the growth of certain bacteria in the rumen the subsequent alteration in the bacterial flora might upset the physiology of rumen digestion.

While this may be highly speculative, several authorities have suggested that the nature of the rumen flora is an important factor conditioning the cow's response to a urea ration. Dr. C. W. Turner, in a review of the role of urea in ruminant nutrition, stresses the importance of determining the optimum conditions for bacterial growth with urea as the source of nitrogen, and asks the questions: "Are the favorable effects from certain rations due to the presence of growth-promoting factors for the rumen organisms? Will some vitamin-like substances or precursors of the vitamins aid in bacterial growth? Are trace elements of any importance?"

Certainly the response obtained when cobalt was added to the urea ration would tend to uphold the theory that the unpalatability of certain urea rations stems from some alteration in the rumen flora and that this change is reversed by the addition of cobalt to the diet.

However, to investigate this theory, further experimentation must be undertaken to demonstrate what qualitative and/or quantitative changes occur in the rumen flora when urea rations with or without cobalt supplementation are fed.

## CONCLUSIONS AND SUMMARY

Results obtained in the experimental work described in this report support the following conclusions:

(1) Individuality of the cow is the most ostensible factor influencing the palatability of a urea ration.

(2) Breed of cow is of some importance; in these experiments Jerseys were more prone to show dislike for urea mixtures than were Holsteins.

(3) Molasses (Betalasses) does, to a certain degree, enhance the palatability of a urea mixture, but even 10 per cent of molasses will not ensure the palatability to all cows of a 3 per cent urea mixture. Further experiments are required to determine the effect on palatability of including molasses in mixtures containing 0.5 per cent and 1 per cent of urea.

(4) The mixing of grain with silage at feeding time will, to a limited degree, overcome the unpalatability of a urea mixture.

(5) The amount of urea in a grain mixture is an important factor in determining the palatability of that mixture. In these experiments the most palatable of all urea grain mixtures were those containing 0 5 per cent of urea.

(6) The response obtained when the urea rations were supplemented with cobalt, together with the apparent non-importance of flavor of these urea mixtures, may be interpreted as evidence of an alteration in the rumen flora (and hence physiology of digestion) induced by the use of urea in the diet.

## REFERENCES

1. Armsby, H. P. U.S.D.A. Bureau of Animal Industry, Bull. 139, p. 49. 1911.
2. Harris, L. E., and H. H. Mitchell. The value of urea in the synthesis of protein in the paunch of ruminants. I. In maintenance. Jour. of Nutrition 22 : 167-182. 1941.
3. Harris, L. E., and H. H. Mitchell. The value of urea in the synthesis of protein in the paunch of ruminants. II. In growth. Jour. of Nutrition 22 : 183-196. 1941.

4. Harris, L. E., S. H. Work, and L. A. Henke. The utilization of urea and soybean oil meal nitrogen by steers. Jour. of An. Sci. 2 : 328-335. 1943.
5. Hastings, W. H. The use of urea in commercial dairy feeds. Jour. Dairy Sci. 27 : 1015-1021. 1944.
6. Johnson, B. C., T. S. Hamilton, H. H. Mitchell, and W. B. Robinson. The relative efficiency of urea as a protein substitute in the ration of ruminants. Jour. An. Sci. I : 236-245. 1942.
7. Hedlin, D. O. Urea as a protein substitute for dairy cows. M.Sc. thesis. April, 1945.
8. McCance, R. A. and E. M. Widdowson. Mineral Metabolism. Annual Rev. of Biochem. 13 : 326. 1944.
9. Mills, R. C., A. N. Booth, G. Bohstedt, and E. B. Hart. Utilization of urea as influenced by the presence of starch in the ration. Jour. Dairy Sci. 25 : 925-929. 1942.
10. Mills, R. C., C. C. Lardinois, I. W. Rupel, and E. B. Hart. Utilization of urea and growth of heifer calves with corn molasses or cane molasses as the only readily available carbohydrate in the ration. Jour. Dairy Sci. 27 : 571-578. 1944.
11. Morrison, F. B. Feeds and Feeding, Appendix, Tables I and III. 20th Edition. The Morrison Publishing Co., Ithaca, New York. 1944.
12. Owen, E. C., J. A. B. Smith, and N. C. Wright. Urea as a partial protein substitute for dairy cattle. Biochem. Jour. 37 : 44-53. 1943.
13. Rupel, I. W., G. Bohstedt, and E. B. Hart. The comparative value of urea and linseed meal for milk production. Jour. Dairy Sci. 26 : 647-664. 1943.
14. Turner, C. W. Recent advances in ruminant nutrition. American Miller and Processor. May, 1945.
15. Weinstein, L., and A. McDonald. The effect of urea, urethane and other carbamates on bacterial growth. Science 101 : 44-45. 1945.

## APPENDIX

ALLOTMENT OF COWS TO THE EXPERIMENTAL RATIONS

| Cow | Experimental number | Breed | Experimental ration | Daily grain allowance at start of experiment | Weeks on experiment | Reaction to urea |
|---|---|---|---|---|---|---|
| | | | | lb. | | |
| SECTION I | | | | | | |
| Nan | 1 | Jersey | 3% urea | 10 | 20 weeks | Some dislike for the 3% urea ration, ate it only when it was mixed with silage. |
| Pilgrim | 2 | Jersey | 3% urea | 5 | 12 weeks | Strong dislike for 3% urea. On 10% molasses mix for 3 weeks then placed on the 3% molasses mix for which she showed no dislike. Off experiment at end of lactation. |
| Katie | 3 | Holstein | 3% urea | 11 | 20 weeks | Very occasional dislike. |
| Rose | 4 | Holstein | 3% urea | 10 | 19 weeks | No refusal. |
| Phila | 5 | Jersey | 3% molasses | 7 | 3 days | Refused grain allowance completely after 3 days. |
| Polly | 6 | Jersey | 3% molasses | 8 | 20 weeks | Some dislike from beginning but went off feed completely in the 15th week. Back to full feed after receiving cobalt for 1 week. |

(Continued on next page)

ALLOTMENT OF COWS TO THE EXPERIMENTAL RATIONS—*Continued*

| Cow | Experimental number | Breed | Experimental ration | Daily grain allowance at start of experiment | Weeks on experiment | Reaction to urea |
|---|---|---|---|---|---|---|
| | | | | lb. | | |
| SECTION I—*Continued* | | | | | | |
| Upsilon | 7 | Jersey | 3% molasses | 6 | 12 weeks | No refusal of grain. Off experiment at end of lactation. |
| Flora | 8 | Holstein | 3% molasses | 10 | 20 weeks | No refusal. |
| Rowena | 9 | Holstein | 3% molasses | 10 | 20 weeks | No refusal. |
| Maxine | 10 | Jersey | 5% molasses | 10 | 8 weeks | Immediate dislike for the ration. Could not be brought to full feed on the 10% molasses mixture so taken off experiment. |
| Theta | 11 | Jersey | 5% molasses | 10 | 18 weeks | Showed occasional dislike during first few weeks but went off feed completely in the 13th week. Grain consumption back to normal after receiving cobalt for 1 week. |
| Clara | 12 | Holstein | 5% molasses | 8 | 12 weeks | No refusal. |
| Louise | 13 | Holstein | 5% molasses | 9 | 9 weeks | No refusal. |
| SECTION II | | | | | | |
| Roma | 14 | Holstein | 1.0% urea | 12 | 10 weeks | No refusal. |
| Rosina | 15 | Holstein | 1.0% urea | 8 | 10 weeks | No refusal. |
| Roberta | 16 | Holstein | 1.0% urea | 11 | 10 weeks | No refusal. |
| Rosy | 17 | Holstein | 1.0% urea | 8 | 10 weeks | No refusal. |
| Edna | 18 | Holstein | 1.0% urea | 10 | 1 day | Completely refused the mixture so transferred to the 0.5% mixture which she ate without refusal for 11 weeks. |
| Hilda | 19 | Holstein | 0.5% urea | 13 | 11 weeks | Showed dislike for the ration throughout the experiment but always consumed her allowance She was offered the 1% mixture in the 8th week, after receiving cobalt, but refused it completely |
| Alpha | 20 | Jersey | 0.5% urea | 11 | 1 day | Immediate refusal. After being fed cobalt for a week she would eat this mixture. |
| Winnie | 21 | Jersey | 0.5% urea | 9 | 7 weeks | Occasional dislike. |

# STUDY OF FERTILIZER UPTAKE USING RADIOACTIVE PHOSPHORUS[1]: II.

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In an earlier paper (2) it was shown that radiophosphorus, $P^{32}$, could be used to measure the uptake of fertilizer phosphorus in wheat plants at different stages of growth.

One of the graphs published indicated that relatively more of the phosphorus in the plant came from the fertilizer in the early stages of growth than at a later stage of growth. However, the first harvest date was already 53 days after seeding and, consequently, it was thought worthwhile to set up experiments with earlier harvest dates. The same soil and type of seed were used as in the first experiment but, owing to the time of year, the experiments were done in the greenhouse.

## FERTILIZER UPTAKE IN EARLY STAGES OF GROWTH

The experiment consisted of six replicates of four harvest dates. Each replicate consisted of three wheat plants in a gallon crock containing 3,200 grams of the same Elstow silt loam soil used in the field experiment. The pots were fertilized at the rate of 25 pounds of ammonium dihydrogen phosphate per acre (calculated on a weight basis). The fertilizer was applied in solution in the region where the seed was planted. A 250 ml. volume of phosphorus solution containing 3.89 grams of $NH_4H_2PO_4$ and 65 ml. of stock radiophosphorus solution[4] was made up and 4.5 ml. were added to each pot. This gave each pot 0.0702 grams of $NH_4H_2PO_4$ or 18.1 mg. of phosphorus and an activity of $5.4 \times 10^5$ counts per minute (as of Oct. 7, the date of planting). The plants grew well and appeared quite healthy. Six pots were harvested every two weeks for a period of eight weeks. The plant and the main roots were used for analysis. The stages of growth of the plant at each harvest date are recorded in Figures 1 to 4.

The results for the analysis of the plants from the four harvest dates for fertilizer and soil phosphorus are shown in Table 1 (see ref. (2) for method). The results are represented graphically in Figure 5. The rates of uptake are shown in Table 2.

The results from the greenhouse experiment on the uptake of phosphorus from the fertilizer and from the soil indicate that:

(*a*) There is no appreciable uptake of soil phosphorus until the plant is two weeks old.

(*b*) The rate of uptake of fertilizer phosphorus is greatest between two and six weeks.

(*c*) The rate of uptake of soil phosphorus increases for each succeeding two-week period.

(*d*) The plant takes up fertilizer phosphorus more rapidly than soil phosphorus for the first four weeks of growth. After four weeks the plant takes up soil phosphorus much more rapidly.

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[1] Part of a thesis for a Master of Science Degree, University of Saskatchewan, Saskatoon, Sask.
[2] Professor of Physical Chemistry.
[3] Graduate student, Soils Department.
[4] The radioactive solution used here contained approximately $4.6 \times 10^7$ counts per minute of radiophosphorus (as of October 7, 1946) in the form of $NaH_2PO_4$ in 100 ml. of water.

Table 1.—The uptake of fertilizer and soil phosphorus by wheat during four periods of growth

| — | Total phosphorus (mgm. P) | Fertilizer phosphorus (mgm. P) | Fertilizer used (%) | Soil phosphorus* (mgm. P) |
|---|---|---|---|---|
| Harvested at 2 weeks | .60 | .27 | 1.48 | −.05 |
| | .54 | .08 | .43 | .06 |
| | .81 | .33 | 1.84 | .09 |
| | .77 | .23 | 1.29 | .15 |
| | .71 | .31 | 1.71 | .02 |
| | .68 | .22 | 1.23 | .08 |
| Average | .68 | .24 | 1.30 | .06 |
| Harvested at 4 weeks | 1.84 | .82 | 4.50 | .64 |
| | 2.55 | 1.35 | 7.45 | .82 |
| | 2.07 | .83 | 4.58 | .86 |
| | 2.16 | 1.07 | 5.92 | .71 |
| | 2.20 | 1.27 | 7.02 | .55 |
| | 2.53 | 1.54 | 8.54 | .61 |
| Average | 2.23 | 1.15 | 6.40 | .69 |
| Harvested at 6 weeks | 4.95 | 2.48 | 9.80 | 2.09 |
| | 6.26 | 2.46 | 12.90 | 3.42 |
| | 4.34 | 1.49 | 11.70 | 2.47 |
| | 5.72 | 1.77 | 13.70 | 3.57 |
| | 6.93 | 2.33 | 13.60 | 4.22 |
| | 6.23 | 2.11 | 8.30 | 3.74 |
| Average | 5.74 | 2.11 | 11.70 | 3.25 |
| Harvested at 8 weeks | 8.31 | 2.69 | 14.90 | 5.24 |
| | 9.98 | 2.85 | 15.80 | 6.65 |
| | 10.60 | 2.54 | 14.00 | 7.68 |
| | 9.91 | 3.09 | 17.10 | 6.44 |
| | 9.58 | 3.18 | 17.60 | 6.02 |
| | 8.65 | 2.80 | 15.50 | 5.47 |
| Average | 9.51 | 2.86 | 15.80 | 6.25 |

* The phosphorus content of the seed was 0.38 mgm. per pot.

Table 2.—The rate of uptake of soil and fertilizer phosphorus by wheat grown in the greenhouse

| Period of growth (weeks) | Rate of uptake of fertilizer phosphorus (mgm. P) | Rate of uptake of soil phosphorus (mgm. P) |
|---|---|---|
| 0–2 | .24* | .06 |
| 2–4 | .91 | .63 |
| 4–6 | .96 | 2.56 |
| 6–8 | .75 | 3.00 |

* Values are expressed as mgm. per 2-week period.


FIGURE 1. (*Upper left*). Stage of growth at two weeks. Plant height, 6-7 inches. Weight of plant material, 0.065 gms.

FIGURE 2. (*Upper right*). Stage of growth at four weeks. Plant height, 17 inches. Weight of plant material, 0.41 gms.

FIGURE 3. (*Lower left*). Stage of growth at six weeks. Plant height, 26 inches. Weight of plant material, 1.41 gms.

FIGURE 4. (*Lower right*). Stage of growth at eight weeks. Plant height, 33 inches. Weight of plant material, 3.17 gms.

The results from the field and greenhouse experiment are combined and shown graphically in Figure 6. The values from the field experiment are plotted so that their stage of growth coincides approximately with the stage of growth of the greenhouse plants. Since the conditions of the two experiments are different, the two sets of results do not fit perfectly. However, they do fit well enough to show the general picture of the rate of uptake. Figure 6 indicates very strikingly that in the early stages of growth practically all the phosphorus taken up by the fertilized plant comes from the fertilizer. As growth continues, the uptake of soil phosphorus becomes increasingly more important until at maturity the greater percentage of the phosphorus in the plant has come from the soil.

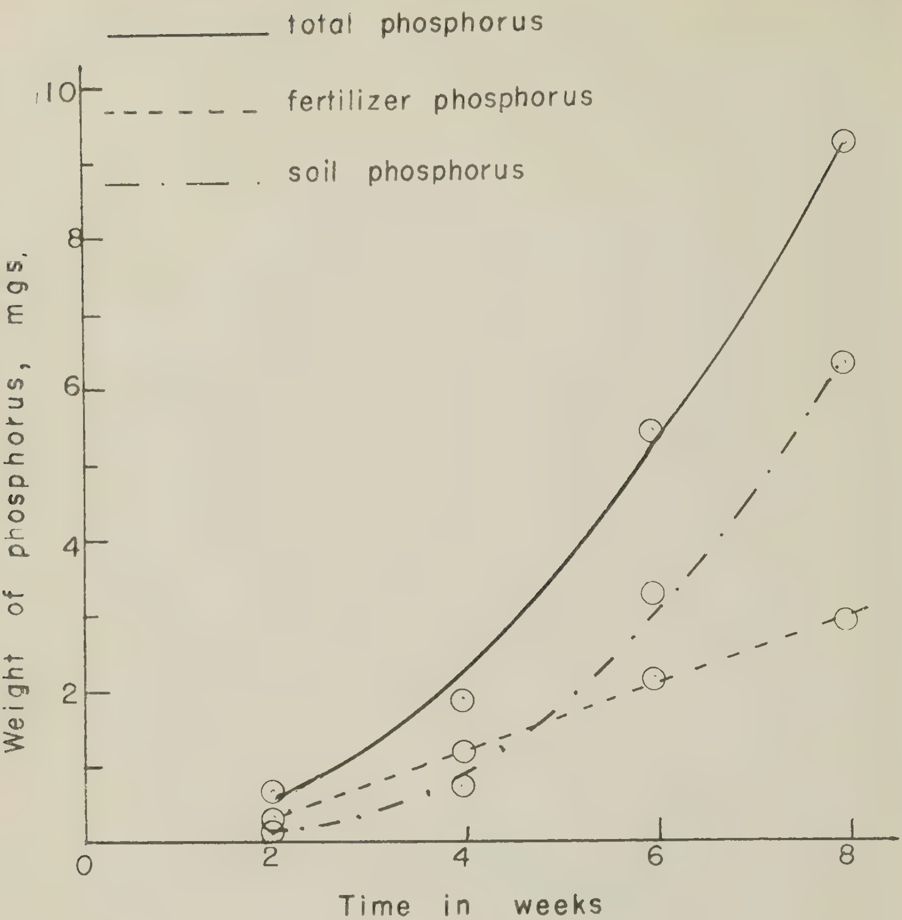


FIGURE 5. Uptake of phosphorus by wheat grown in the greenhouse; fertilized wheat.

## THE INCREASED USE OF SOIL PHOSPHORUS BY PHOSPHATE FERTILIZED WHEAT

In the past the recovery of phosphate fertilizer by a wheat crop has generally been determined by a comparison of the uptake of phosphorus by the fertilized and unfertilized crops. The extra phosphorus in the fertilized crop has been taken as the quantity coming from the fertilizer. Russell and Watson (1) in a report on the Rothamstead experiments used this method for determining the per cent recovery. They found 8 to 25 per cent recovery by the first crop when fertilized at the rate of 70 pounds of $P_2O_5$ per acre. Experiments with radiophosphorus, however, show that the phosphorus in the fertilizer is utilized by the wheat early in the growing season and that very little of the fertilizer phosphorus was used after the plant reached the heading stage. The addition of phosphorus stimulates plant growth and hence it is possible that the increased growth of the

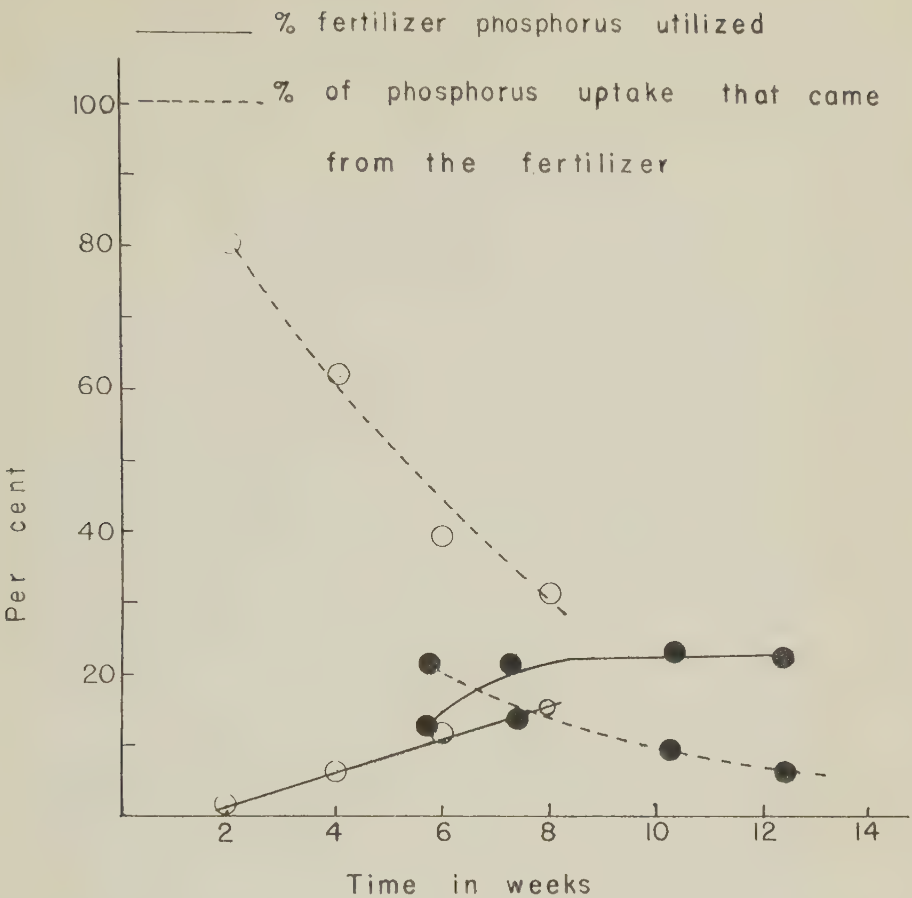


FIGURE 6. Combined results for fertilizer uptake in the field and greenhouse. Field, ●; greenhouse, ○.

fertilized crop will use more soil phosphorus than the unfertilized crop. If this occurs, the increased amount of phosphorus taken up by the fertilized wheat would not represent the amount of phosphorus which came from the applied fertilizer.

The determination of the extra soil phosphorus used can be made with the aid of a radioactive tracer. By mixing radiophosphorus with the phosphorus of the fertilizer, the fertilizer phosphorus used by the wheat can be measured quantitatively. The amount of soil phosphorus used by the fertilized crop can then be determined by subtracting the phosphorus coming from the seed and the fertilizer from the total phosphorus present in the plant.

An experiment was undertaken to show the rate of uptake of both soil and fertilizer phosphorus for two-week intervals over a period of eight weeks. This experiment was done in conjunction with the greenhouse experiment

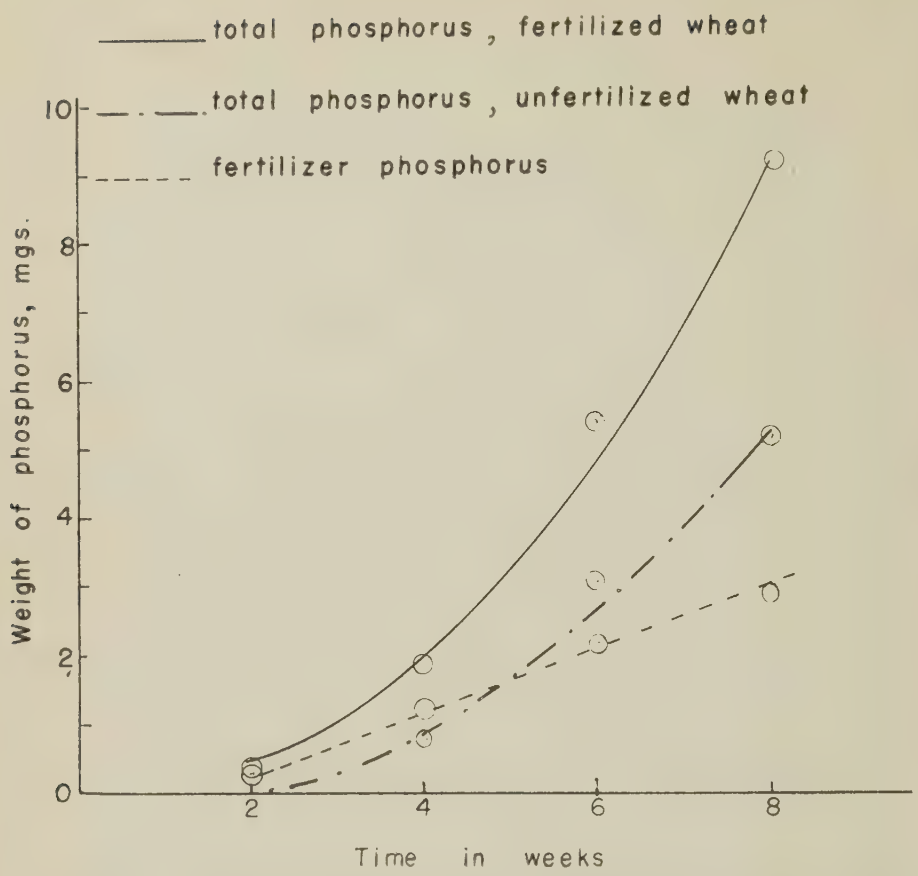


FIGURE 7. Uptake of phosphorus by wheat grown in the greenhouse, fertilized and unfertilized wheat.

on the extent and rate of utilization of phosphate fertilizer previously mentioned. In addition to the six replicates of fertilized wheat harvested at each of four harvest dates, there were six replicates of unfertilized wheat which were harvested simultaneously.

## EXPERIMENTAL RESULTS

The average results are brought together in Table 3, and a comparison of the rates of uptake of phosphorus by the fertilized and unfertilized wheat is shown in Table 4.

The abbreviations used are:

$P_T$ — the total phosphorus in the plant.

$P_G$ — the total phosphorus in the grain seeded = 0.38 mgm.

$P_F$ — the phosphorus coming from the fertilizer (as determined from the radioactivity).

$P_S$ — the phosphorus coming from the soil. In unfertilized plants this is $P_T - P_G$. In fertilized plants it is $P_T - P_G - P_F$.

$P_I$ — the increase in amount of phosphorus coming from the soil in the fertilized plants. That is; $P_S$ (for fertilized plants) — $P_S$ (for unfertilized plants).

TABLE 3.—AVERAGE VALUES FOR THE PHOSPHORUS UPTAKE OF WHEAT SOWN WITH AND WITHOUT FERTILIZER

| Treatment | Plant weight | $P_T$ | $P_F$ | $P_S$ | $P_I$ | % $P_I$ is of $P_S$ |
|---|---|---|---|---|---|---|
| Grain | | 0.38 | | | | |
| 2-week growth | | | | | | |
| Unfertilized | .061 | .34 | | −.04 | | |
| Fertilized | .065 | .68 | .24 | .06 | .10 | |
| 4-week growth | | | | | | |
| Unfertilized | .321 | 1.16 | | | | |
| Fertilized | .406 | 2.23 | 1.15 | .69 | −.09 | |
| 6-week growth | | | | | | |
| Unfertilized | 1.10 | 3.40 | | 3.02 | | |
| Fertilized | 1.41 | 5.74 | 2.11 | 3.25 | .23 | 7.1 |
| 8-week growth | | | | | | |
| Unfertilized | 2.57 | 5.50 | | 5.12 | | |
| Fertilized | 3.17 | 9.51 | 2.86 | 6.27 | 1.15 | 18.1 |

TABLE 4.—A COMPARISON OF THE RATE OF UPTAKE OF PHOSPHORUS FROM THE SOIL BY FERTILIZED AND UNFERTILIZED WHEAT

| | Period | | | |
|---|---|---|---|---|
| | 0–2 wks. | 2–4 wks. | 4–6 wks. | 6–8 wks. |
| Unfertilized | | | | |
| $P_S$ | 0* | .80 | 2.24 | 2.10 |
| Fertilized | | | | |
| $P_T$ | .30 | 1.76 | 3.52 | 3.76 |
| $P_F$ | .24 | .92 | .96 | .76 |
| $P_S$ | .06 | .64 | 2.56 | 3.00 |
| $P_S$ (fertilized − unfertilized) | .06 | −.16 | .32 | .90 |
| Per cent increase in use of soil phosphorus by fertilized wheat | — | — | 14.00 | 43.00 |

* All rates expressed as mgm. of phosphorus per two weeks.

The results from Tables 3 and 4 are plotted in Figures 7, 8 and 9.

## DISCUSSION OF RESULTS

The results of this experiment indicate that:

1. There is no appreciable difference in uptake of soil phosphorus by the fertilized and unfertilized wheat for the first four weeks of growth.

2. During the period from 4 to 6 weeks, the fertilized wheat took up 14 per cent more phosphorus from the soil than did the unfertilized wheat.

3. During the period from 6 to 8 weeks, the increased uptake was 43 per cent.

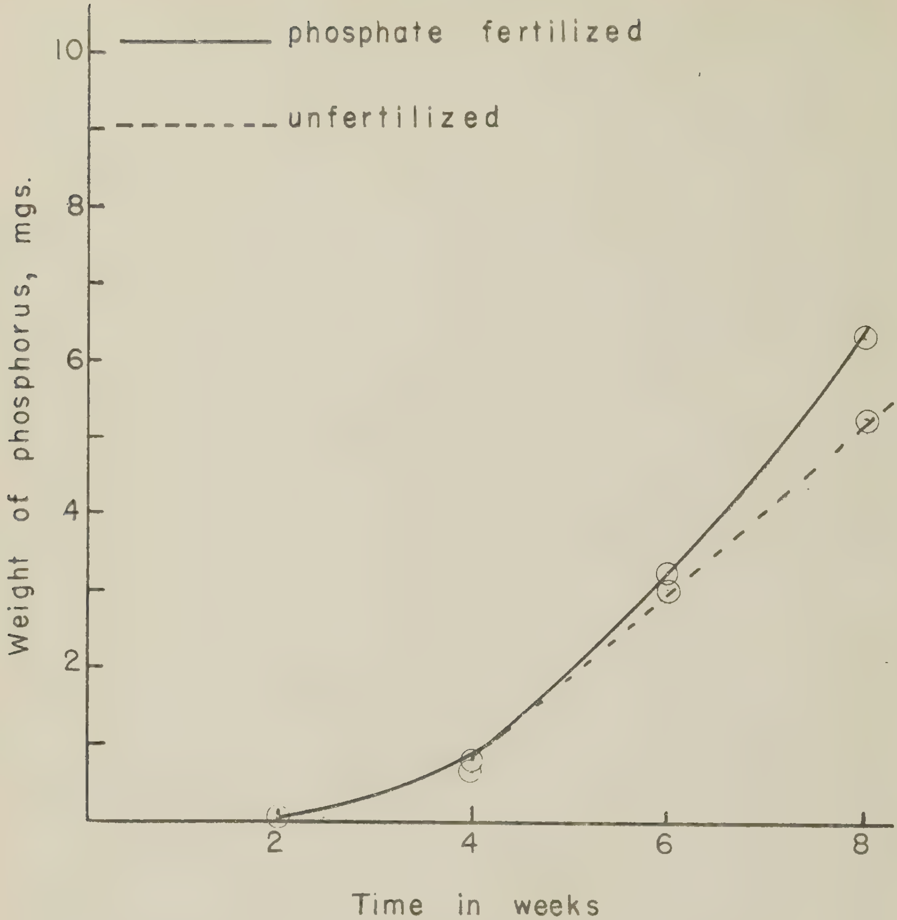


FIGURE 8. Uptake of soil phosphorus by fertilized and unfertilized wheat.

These wheat plants were grown only one week past heading stage. The small negative results obtained for the first two harvest periods can be accounted for by loss of roots and by experimental error due to the small amounts of total phosphorus being measured.

A very significant point which is shown by these results is the difference between the recovery of applied phosphorus as measured by the tracer method and the recovery as measured by the difference in total phosphorus uptake between the fertilized and unfertilized crop. After 8 weeks the actual amount of fertilizer phosphorus recovered was 2.86 mgm. or 15.8 per cent. The difference between the total phosphorus uptake of the fertilized and unfertilized crop is 4.01 mgm., which would show a recovery of 22 per cent. The result obtained by difference for the recovery of the applied phosphorus would be in error by $\frac{1.15}{2.86}$ or almost 40 per cent. While the extent of the error may vary with the soil and the season, it remains true that the old method of determining fertilizer uptake is unsound and can lead to large errors.

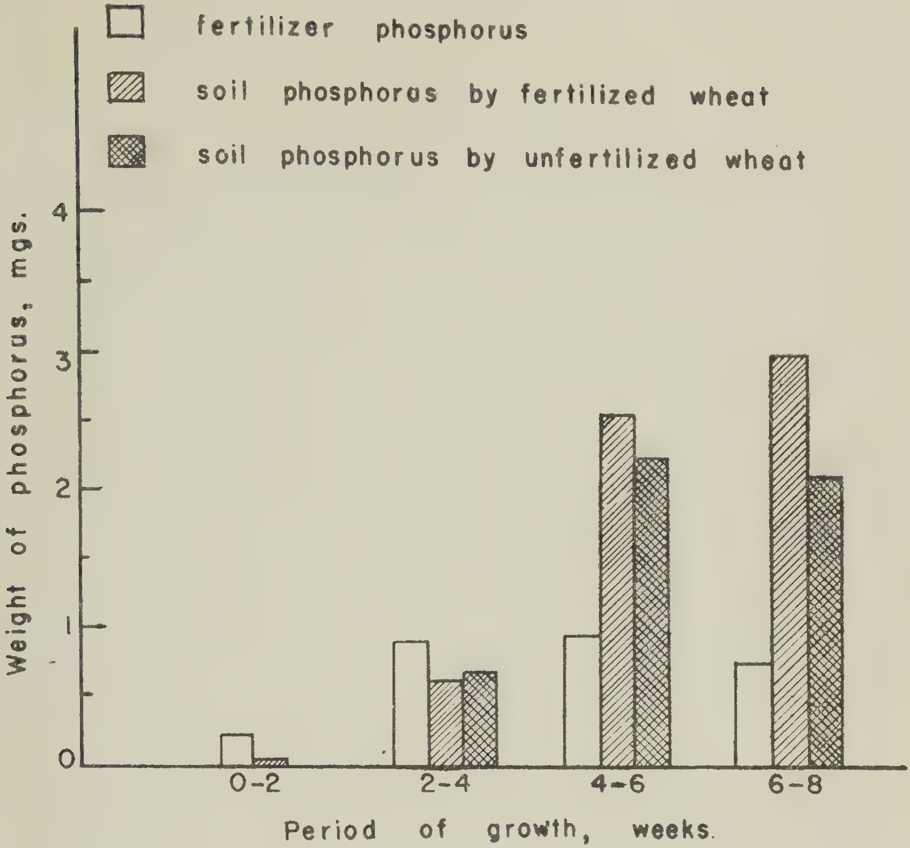


FIGURE 9. The rate of uptake of fertilizer phosphorus and of soil phosphorus by fertilized and unfertilized wheat expressed as mgm. per two week period.

## SUMMARY

Radioactive phosphorus has been used to show that, in the early stages of growth, practically all the phosphorus taken up by the fertilized plant comes from the fertilizer.

Comparison with control plants indicates that the fertilized plants took up considerably more soil phosphorus than the unfertilized plants.

It has been shown that the old method of determining fertilizer uptake can lead to large errors.

## ACKNOWLEDGMENTS

Grateful acknowledgment is made to the National Research Council of Canada for financial support and to Dean Cowie of the Department of Terrestrial Magnetism, Washington, and the Consolidated Mining and Smelting Company of Canada for assistance. We are also grateful to Dr. Dion of the Soils Department for helpful advice.

## REFERENCES

1. Russell, E. J., and D. J. Watson. The Rothamstead field experiments on the growth of wheat. Technical Communication 40, Imperial Bureau of Soil Science, Harpenden, England. 1940.
2. Spinks, J. W. T., and S. A. Barber. Study of fertilizer uptake using radioactive phosphorus. Sci. Agr. 27 : 143-156. 1947.

# THE MAINTENANCE OF ORGANIC MATTER IN THE BROWN SOILS[1]

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The western pioneer, as he followed his ox- or horse-drawn breaking plow across the virgin prairie, did not realize that he was bringing into production an area destined to produce the highest quality wheat in the world. It was definitely a new agricultural field into which the pioneer had ventured and many were the problems with which he and his followers would have to contend. These were new soils and by "new" is meant soils differing from those cultivated in any other part of the world, for they had developed under a particular set of climatic conditions. The productive capacity of the soil and the quality of the product have been definitely proven to rank high. The millions of bushels of high quality grain that have flowed out of the prairies since the first shipment of 860 bushels of wheat from the Red River valley in 1876 are ample evidence of this fact.

During the past seventy years, many serious production problems have arisen, which, in some cases, have been referred to as sounding the death-knell of prairie agriculture.

The first problem or need was for a wheat suitable to the climate and the soil. This was met by the introduction of Marquis, that king of wheats, which reigned for many years over the west.

The cerealists have since produced early-maturing varieties of wheat and other cereals, which are pushing the grain-growing area ever northward, thus adding to the acreage of potential farm-land. The second problem was that of drought. Summerfallowing was introduced by the Dominion Experimental Farm at Indian Head in 1885 because of a shortage of horse-power rather than by design. This practice has given a partial control over this recurring climatic condition. Rust wrought havoc with the crops in certain years, and again the cerealist came to the rescue with varieties of grain resistant to rust. The entomologist, and later the cerealist, have developed methods and crops that have reduced the damage caused by insect pests. Soil erosion by wind became a serious problem and the farmer, by trial and error, found a means of partial control. The more recent information supplied by the soil specialist, plus the results of the trial-and-error method, now offer considerable assurance that the devastation of the dusty Thirties need not recur. The recent rapid development of selective herbicides gives promise of more effective control of the noxious weeds, which should increase grain production. These are the main production problems that have confronted the prairie agriculturists and, while the problems have not been eliminated, the farmer has at his disposal suitable varieties of grain and sufficient information on cultural practice to enable him to combat fairly successfully these destructive agencies. If the scientists engaged in agricultural research continue to meet with the same success as in the past — and this can be taken for granted — agriculture on the prairie should not be seriously handicapped, in so far as the problems mentioned are concerned.

[1] Contribution from the Experimental Farms Service, Department of Agriculture, Ottawa, Canada.
[2] Agricultural Scientist.

## SOIL DETERIORATION

The one factor that may have the most influence on future crop production, and which has received the least attention, is that of soil deterioration. How long will the prairie soils continue to produce profitable yields of high quality grain? Are the present methods of farming exhausting the soils at a rapid rate? These are problems worthy of serious consideration. As previously mentioned, the western farmer is working with new soils for which there is no backlog of knowledge in regard to cultural practice built up by years of experience and research. The present methods of cultivation are, in general, the result of trial and error, and, in many cases, the education has been a costly one. Much of the disaster of the dusty Thirties can be traced to the bare fallow and dust mulch theories advocated at one time. It is only recently that a determined attempt has been made to break away from the theories of soil husbandry handed down from areas of more plentiful rainfall. It is doubtful if sufficient information is available, at the present time, to definitely outline a practical, permanent system of agriculture for the prairies.

## BROWN SOILS

This paper so far has dealt with the prairie area as a whole, but the remainder will deal more specifically with the brown soil zone, though in many cases the statements made will apply to more or less of the dark brown soil zone.

Dr. F. A. Shutt, who was Dominion Chemist for many years, drew attention in 1905 and again in 1925 (7) to the rapid loss of nitrogen and organic matter after the prairie soils were brought under cultivation. In 1937, an investigation was started by the Department of Soils, University of Alberta (1, 4) in conjunction with the Dominion Experimental Farms Service, to determine the effect of cultivation on the chemical composition of some western soils. There have been numerous articles in newspapers and periodicals dealing with the deterioration of western soils or methods for stabilizing western agriculture but they have included very little definite information to substantiate the statements made.

There are certain facts that have been proven by actual analyses of soils, or established by reliable figures and observations, which must be accepted. The research work of Caldwell, Newton, Wyatt and Brown (1, 4) has shown that there has been a definite loss of nitrogen and organic matter from the brown soils since they were brought under cultivation. This loss has amounted to approximately 18 per cent of the nitrogen and 20 per cent of the organic matter as determined by comparing adjacent virgin and cultivated land. The data also indicate that the loss was about one-half as rapid in soils cultivated for 28 years as in soils cultivated only 9 years. Shutt (7) also mentioned a slower rate of loss as the soils were cultivated for a longer period of time.

These facts immediately raise the question: Has this loss of nitrogen and organic matter resulted in a decrease in productivity or/and an increase in the susceptibility to erosion? The answer to the second part of the question is definitely "yes", for it is an accepted fact that most soils are relatively resistant to erosion for a few years after breaking. However, the fact has not been established that they are more susceptible to erosion 25

years after breaking than they were 10 years previously. The effect of the loss of nitrogen and organic matter on productivity cannot be answered so easily.

## YIELD DATA

Yield data, which are the most reliable indicators of productivity, are available for various crop districts, but only for 25- or 30-year periods. These data do not take into consideration such factors as percentage of new land, fallow, hail, frost, rust, insect damage or variety of grain. There has also been some abandonment of marginal land with only the better land being kept under cultivation.

The average wheat yield for the 30-year period, 1916-1945, for crop districts 2, 3, 4, 6 and 7 in Saskatchewan was 12.7 bushels. These districts take in all the brown and most of the dark brown soils. For the first 10-year period, 1916-1925, the average yield was 13.4 bushels and for the last 10 years, 1936-1945, it was 12.5 bushels, a decrease of approximately 1 bushel and only 0.2 bushels below the 30-year average. The last period includes the crop failure year of 1937, when the average yield for the districts mentioned was below 1 bushel, and the year 1942 with an average of 26.6 bushels, which was the highest in the 30-year period.

Considering only crop district No. 3 in Saskatchewan, which extends from the South Saskatchewan River about 30 miles north of Swift Current to the international boundary, the average yield for the 30-year period, 1916-1945, was 12.1 bushels. The average for the last 5 years was 14.1 bushels, which was exceeded by only the second and third 5-year periods with averages of 18.2 and 14.9 bushels. The average annual precipitation for the second and third 5-year periods was 15.3 and 16.3 inches, respectively, compared with 14.1 for the last 5 years and a 30-year average of 14.7 inches.

In Alberta, crop districts 1, 3, 5 and 7, which extend up the eastern side and take in most of the brown soils, have an average wheat yield for the period 1921-1945 of 12.7 bushels per acre. The average yield for the first 5 years of this period was 12 bushels and for the last 5 years 11.5 bushels. The highest yearly average was in 1927 and the second highest in 1942.

Reliable yield data are available in the records of the Dominion Experimental Farms and Stations, but these cover periods of only 35 years at the most. At Scott and Swift Current, the records show that the average yield of wheat on fallow for the last 10 years is lower than the average for the whole period. This might be expected, for the experimental areas were new land at the beginning of the period. At Lethbridge, a 2-year rotation of wheat-fallow, extending over a 35-year period, has given an average yield of 26.8 bushels and an average of 28.1 for the period 1937-1946. Continuous wheat at Lethbridge has averaged 11.6 for the same 35-year period and 12.4 bushels for the 1937-1946 period. These fields were new land to start with and have remained relatively free of weeds.

At Swift Current, wheat has been grown continuously and in a 2-year rotation of wheat-fallow on the same soil in tanks since 1923. These tanks have been kept free from weeds and all loss has been kept to a minimum. The data from these experiments are the most reliable for showing the effect of cropping on soil deterioration but the experiment extends over a

relatively short period. The tanks are 15 inches in diameter and 5 feet deep and were filled with layers of soil corresponding to similar depths in the field. All straw was removed when the crops were harvested and no plant residue (except the crowns and roots) and no fertilizer of any kind was added to the soils in the tanks.

The average yield of wheat on the fallowed land has been 32.1 bushels for the entire period and 31.5 bushels for the last 9 years, 1938-1946, inclusive. For the first 5-year period the yield was 46.2 bushels with a rainfall of 16.4 inches; for the second 5-year period, 32.0 bushels with a rainfall of 11.8 inches, and for the last 5-year period 34.2 bushels with a rainfall of 14.6 inches. The tanks seeded to wheat every year have given an average yield of 16.1 bushels for the entire period and 20.8 bushels for the last 9 years. The data for the fallowed land show a drop in yield after the first 4 or 5 years and then considerable uniformity, while the data from the continuous cropping show little change. It is unfortunate that similar data are not available for a longer period, as well as for other soils and climatic conditions.

From the data presented, it seems evident that a drop in yield may take place during the first 4 or 5 years, but, after this initial decrease, there is a levelling off and very little, if any, further decrease. The fact that fertilizers have little or no effect on yield of crops on the brown soils is further evidence that sufficient plant nutrients are available to produce all the crop growth for which there is water. Crops on the brown soils are always dark green in colour under favourable moisture conditions, indicating an adequate supply of nitrogen. Soil samples from even the oldest fields form nitrates very readily under laboratory conditions, reaching concentration of 30 to 60 p.p.m. of nitrate nitrogen in a 3-week period. Soil samples collected at seeding-time from 20 or more fields of fallow land have shown an average nitrate nitrogen content of 18-20 p.p.m. in the 0-6″ layer, which is sufficient nitrogen for an 18-20 bushel crop of wheat. Although there has been a definite loss of nitrogen and organic matter from the brown soils, the available data do not indicate that the average crop yield is decreasing.

## GRASS AND LEGUMES IN ROTATION

The short rotation of wheat-fallow or wheat-wheat-fallow, which has been followed by most of the prairie farmers, has been called soil mining and listed as the chief cause of soil erosion and the main contributing factor to the rapid loss of organic matter. The suggested alternative to such a method has been the inclusion of grass and legumes in the rotation. There is no question about a soil seeded to grass being relatively safe from erosion, but there are certain factors that have a direct bearing on the practical aspects of such a procedure.

There is, at the present time, no legume particularly adapted to the dry land condition, thus the use of legumes cannot be depended on for the replenishment of the nitrogen content of the soil. The next problem is that of getting a good stand of grass established. Competent agrostologists state that, under favourable climatic conditions, some hay or pasture might be produced the first year after seeding, but, in general, it would be the second year before any appreciable return could be expected. Under

adverse climatic conditions (and such are frequent in the brown soil zone), a longer period might be required. It is indeed unfortunate that the grasses most suitable for this area are relatively slow in becoming established.

After a grass crop has become established, what yield can be expected? The average yield of dry land hay at the Swift Current Experimental Station is 750 pounds, while at Scott and Lethbridge, the average yield has been approximately 1300 and 1500 pounds (2), respectively. From the yield data pertaining to cereal crops, it is evident that more feed could be raised at Swift Current by seeding the land to an annual cereal crop than by putting it in grass. Just what use the farmer would make of the hay or pasture, if one-quarter or more of his land were in grass, is outside the problems being discussed in this paper.

Stevenson and White (6) determined the amount of fresh fibre in the sod of crested wheat, brome and slender wheat grass for stands from 1 to 8 years old. These were experimental plots at the University of Saskatchewan on a clay loam soil, where good stands had been obtained. The climatic conditions were more favourable than in much of the brown soil zone. The authors came to the conclusion that 5 years in crested wheat grass or brome were required to produce 50 per cent as much fibre as found in a native sod. The results show approximately 6000 pounds of fresh root fibre in sod from 5-year stands. Slender wheat grass produced less fibre than the other two grasses. These results are in keeping with the work of Pavlychenko (5).

Data collected by the Soil Research Laboratory from stands of crested wheat grass on sandy soils show an increase of 2 to 3 tons per acre in organic matter in 6 years where good stands of grass were obtained. At 3 locations, where poor stands were obtained, there was a loss of 2 to 3 tons of organic matter in the 6 years. The first samples were taken within a year after the fields had been seeded to grass. On loam soils, where good stands of crested wheat were established, there was an increase in organic matter of approximately 20 per cent or 5 tons per acre in 6 years. These figures show that the increase in organic matter is relatively slow under the climatic conditions of the area under consideration.

From the information available in regard to the grasses which are suitable for the brown soil zone, it would appear advisable to leave the land in grass for a longer period than four years. Six or eight years would appear a more logical period.

## LOSS OF ORGANIC MATTER

What is the result on crop yield when the sod is broken up and how rapid is the loss of organic matter? Data from Dominion Experimental Sub-stations in south-western Saskatchewan show smaller yields of wheat from crested wheat grass sod broken the previous year than from fallowed land in the regular rotation. This reduction is probably connected with a moisture problem. Field observations indicate that increased resistance to wind erosion lasts only as long as the mechanical binding effect of the roots. Analyses at the Soil Research Laboratory have shown no appreciable change in crumb structure, where land was in grass for only 4 years. There is some indication of an increase in the water stable aggregates, where the land has been in grass for a longer period.

TABLE 1.—COMPOSITION OF SAMPLES AND LOSS OF ORGANIC MATTER AS CARBON DIOXIDE

| | Cultivated land | Native sod | C.W. sod | Brome sod |
|---|---|---|---|---|
| Number of samples | 13 | 10 | 5 | 2 |
| Total nitrogen, % | 0.216 | 0.277 | 0.254 | 0.261 |
| Total organic matter, % | 3.43 | 4.89 | 4.50 | 4.48 |
| O.M./N ratio | 15.87 | 17.65 | 17.71 | 17.16 |
| O.M. lost in 31 days, % | 1.54 | 2.49 | 3.14 | 2.71 |
| Relative loss in first 15 days, % | 55.3 | 58.5 | 55.6 | 61.4 |
| Relative loss in last 16 days, % | 44.7 | 41.5 | 44.4 | 38.6 |
| Monthly loss of O.M. based on 16 day period, lb./acre | 924 | 1930 | 2520 | 1776 |

Lehane and Staple (3) found that samples of crested wheat grass sod lost approximately 9.0 per cent of the organic matter in a 5-month period and 15.1 per cent in 10 months, when kept under favourable conditions in the greenhouse. The sod samples were dried, coarsely pulverized, then placed in glazed crocks and watered at periodic intervals. These conditions would probably be equal to two years or more decomposition in the field. It was found that the loss of organic matter was most rapid in the coarse textured soils, less rapid in the medium textured, and slowest in the fine textured soils.

Analyses were made of native sod at the time of breaking and again after 7 years of cultivation. The results showed an average loss of 22 per cent of the organic matter. Brome and crested wheat grass sod lost approximately as much organic matter and nitrogen in 2 years after breaking as had been accumulated in the 4 years that these areas were in grass.

An experiment was set up in the laboratory and the rate of loss of organic matter calculated from the evolution of carbon dioxide. Paired samples of sod and cultivated soil were collected, then dried and pulverized in a hammer mill over a 32-mesh sieve. This reduced all organic matter to the same relative size and gave a uniform mixture. Triplicate samples of 200 gm. of each soil were placed in flasks, moistened to field capacity and stoppered. The evolution of carbon dioxide was measured by aeration of the flasks at periodic intervals, absorbing the carbon dioxide in sodium hydroxide and titrating. The data in Table 1 show the results of this experiment. In each case, the results are the average of all determinations for each class of samples. The amount of organic matter was calculated by use of the factor 1.724 times organic carbon. The data show that the cultivated soils lost organic matter at the rate of 1035 lb. per acre during the 31-day incubation period, while the native sod lost 2325 lb., crested wheat sod 2842 lb., and brome sod 2306 lb. The samples lost approximately 55 per cent of the total loss during the first 15 days of incubation.

This shows the reduction in the rate of decomposition in a period of only 31 days. The period of incubation was extended to 69 days for some of the samples. This longer period showed a fairly constant rate of $CO_2$ evolution after 40 days. The samples of cultivated soil reached this constant rate more quickly than the sod samples. A comparison of the first and last 15 days of the 69-day period showed that the cultivated soils were losing carbon approximately 2/5 as fast as during the first period and the sod samples at 1/3 of the original rate. The cultivated soils containing less fresh organic material showed less reduction, indicating a more stable rate of decomposition. When calculated on an acre basis, the cultivated soils lost organic matter for the last 15 days at the rate of 450 lb. per month and the native sod 834 lb. per month. Rates of loss under field conditions would be less than under the conditions of the laboratory experiments as conditions would be less favourable for bacterial activity.

In another laboratory experiment, where finely ground straw was mixed with soil and incubated under favourable conditions, there was a loss of 26 per cent of the organic matter as carbon dioxide in the first 15 days and 37.1 per cent in 65 days. These experiments tend to emphasize the rapid loss during the early stages of decomposition. This is attributed to the rapid breakdown of the starches, sugars and other carbohydrates in the fresh plant material, which are easily decomposed.

The use of the combine harvester, which leaves all straw on the field, is almost universal in the brown soil zone. This raises the question of the effect of this plant residue on the organic matter content of the soil. An average yield of 12 bushels of wheat would mean that 1080 pounds of straw per acre would be returned to the soil. This takes no account of roots or weeds which would increase the total. On the basis of a monthly loss of 450 pounds per acre, as calculated from the laboratory experiment, this addition would almost compensate for the yearly loss, as conditions for bacterial activity would be less favourable in the field.

Newton *et al.* (4) reported an average loss of 13,570 pounds of organic matter per acre from the 0-6″ layer of the brown soils. The average period under cultivation was 16 years giving an annual loss of 848 pounds. An average yield of 10 bushels of wheat would give 900 lb. straw on the basis of the crop being 40 per cent grain; thus the addition would be equal to the loss. The 900 lb. of straw would be increased by roots and weeds. The fallow year, when no crop is grown, must also be considered, though in many cases a fair crop of weeds is turned down. The rate of loss as reported by Newton *et al.* (4) is less than calculated from the evolution of carbon dioxide in the laboratory experiments, but is probably more representative of field conditions.

A field experiment has been carried on by the Soil Research Laboratory in which one ton of straw per acre has been added every second year during the fallow period of a 2-year rotation. Four applications of straw have been made to date. Analyses of soil samples from the plots to which straw has been added and adjacent check plots show that the straw plots have a slightly higher content of nitrogen and organic matter. While the application of one ton of straw every 2 years may be at a higher rate than returning all plant residue, this rate has more than compensated for the annual loss.

There are insufficient data to justify a definite statement but it is evident that the returning of all crop residue to the land would materially reduce if not compensate for the annual loss of nitrogen and organic matter. Thus the return of all crop residue to the land must be considered as serving a three-fold purpose. The trash cover is the most effective means of controlling soil erosion; it aids in the conservation of moisture and the maintenance of the organic matter and nitrogen content of the soil.

The seeding of certain lands to grass has definite advantages and is recommended for coarse texture soils, which are subject to erosion; but the existing data will not justify this recommendation as a practical method of increasing the nitrogen and organic matter content of the medium and fine textured brown soils.

## SUMMARY

1. It has been shown that a rapid loss of nitrogen and organic matter takes place when the brown soils are brought under cultivation. This loss has amounted to approximately 20 per cent and takes place within a few years after breaking. The rate of loss is much slower in soils that have been cultivated 15 or 20 years.

2. Crop yield data for the crop districts in the brown soil zone of Alberta and Saskatchewan do not indicate any appreciable decrease in yield during the 25- to 30-year periods for which data are available.

3. Yield data for specific experiments show a decrease in yield during the first 4 or 5 years after ploughing up grass land; but, after this initial period, the yields show no definite decrease that can be attributed to a loss in productivity.

4. The loss of nitrogen and organic matter after ploughing of grass land is more rapid than the accumulation while in grass.

5. The return of all crop residue is recommended as the most practical means of compensating for the loss of organic matter from the medium and fine textured soils of the brown soil zone.

## REFERENCES

1. Caldwell, A. C., F. A. Wyatt, and J. D. Newton. Effect of cultivation and cropping on the chemical composition of some western Canada prairie soils. Sci. Agr. 19 : 258-270. 1939.
2. Hopkins, E. S., and A. Leahey. Crop rotations in the prairie provinces. Dominion of Canada, Department of Agriculture Pub. 761. 1944.
3. Lehane, J. J., and W. J. Staple. The effect of crested wheat grass on some physical and chemical characteristics of soil. Sci. Agr. 23 : 509-517. 1943.
4. Newton, J. D., F. A. Wyatt, and A. L. Brown. Effect of cultivation and cropping on the chemical composition of some western Canada prairie province soils. III. Sci. Agr. 25 : 718-737. 1945.
5. Pavlychenko, T. Root systems of certain forage crops in relation to the management of soils. National Research Council of Canada Pub. No. 1088. 1942.
6. Stevenson, T. M., and W. J. White. Root fibre production of some perennial grasses. Sci. Agr. 22 : 108-118. 1941.
7. Shutt, F. T. Influence of grain growing on the nitrogen and organic matter content of the western prairie soils of Canada. Dominion of Canada, Department of Agriculture, Bull. No. 44 N.S. 1925.

## ERRATUM

In the article, "The influence of antibiosis in the pathogenicity of *Helminthosporium sativum*", by P. M. Simmonds, published in the December, 1947, issue of "Scientific Agriculture", Vol. 27, No. 12, an error occurred in the "References", page 632. In Reference No. 13, the author is "Sanford, G. B.", and the name of W. C. Broadfoot should be omitted.

## ERRATUM

In the article, "The stability of iodine in iodized rock salt", by W. M. Davidson and C. J. Watson, published in the January, 1948, issue, Vol. 28, No. 1, on page 3, under list of reagents used (e) should read "Potassium *nitrite*".

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1. Newton tercentenary celebrations . . . Published for The Royal society. Cambridge, University press, 1947. 92 p. il. figs.
2. The Assiniboine Basin; a social study of discovery, exploration and settlement. Martin Kavanagh. Winnipeg, Public press, ltd., 1946. 282 p.

## AGRICULTURAL CREDIT

3. Canadian farm loan board. Annual report, 1947. Ottawa, King's printer, 1947. 23 p.
4. All about credit societies. E. Russell. St. John's, 1947. 46 p. At head of title: Newfoundland. Dept. of natural resources. Cooperative division.
5. Suggestions for supervisory committees of Ontario credit unions. J. B. Nelson. Toronto, Dept. of agriculture, 1947. 31 p.

## AGRICULTURAL EDUCATION

6. A hasty glance at the information program of the Federal extension service. Lester A. Schlup. Wash., U.S. Dept. of agriculture. Extension service. Division of extension information, 1947. 51 p. (processed).

## AGRICULTURAL ENGINEERING

7. New developments in garden tractors. W. J. Adams, jr. (In Agricultural engineering, January, 1948. pp. 15-17)
8. Preparation of cribs for artificial drying. Wash., U.S. Dept. of agriculture. Bureau of plant industry, soils, and agricultural engineering (1947 6 p. figs. (processed) (Information series no. 83)
9. American mechanization in the Piedmont. Raleigh, 1947. 35 p. figs. (North Carolina agricultural experiment station. Technical bulletin 84)
10. The use of soil heating cable for protection of water systems. Prepared by Central Vermont public service corporation. Amherst, 1947. 3 p. il. (processed) (Massachusetts. University. Engineering extension series no. 123)

## BOTANY

11. Factors in botanical publication and other essays. Neil E. Stevens. Waltham, Mass., Chronica botanica co., 1947. pp. 121-204. (Chronica botanica, vol. 11, no. 3)
12. New species of Liliaceae with six somatic chromosomes. A. Quintanilha and A. Cabral. (In South African journal of science. vol. XLIII, July, 1947, pp. 167-170)
13. Les lichens, les mousses et les hépathiques du Québec et leur rôle dans la formation du sol arable dans la région du bas de Québec de Lévis à Gaspé. Ernest Lepage. Quatrième fascicule. Les mousses. Québec, 1947. (Extrait, avec changement de pagination du Naturaliste Canadien, 72 : 241-265, 315-338; 73 : 33-56, 101-134, 207-232, 395-411)
14. Collectanea botanica a Barcinonensi botanico instituto edita. vol. I, fasc. II. Barcelona, 1947. pp. 107-198. il.

## CHEMISTRY—CHEMIC TECHNOLOGY

15. Some aspects of nuclear chemistry. H. J. Emeléus. London, Royal institute of chemistry of Great Britain and Ireland, 1947. 19 p.
16. Standard methods for the examination of water and sewage. Ninth edition—second printing (1947). New York, American public health association, 1946. 286 p. figs. tabs. References through the text.
17. American society of brewing chemists. Proceedings of the eleventh annual meeting, 1946. Milwaukee, 1946. figs. tabs.

## CHEMISTRY—CHEMIC TECHNOLOGY—Continued

18. Perilla. "Know your oilseeds". One in a series of articles about oilseed crops which compete with soybeans. R. O. Weibel and W. L. Burlison. (In The soybean digest. vol. 8, no. 3, January 1948. pp. 14-15)
19. Glutinosin: a fungistatic metabolic product of the mould Metarrhizium glutinosum S. Pope. (In Royal society. Proceedings. Series B. Biological sciences. vol. 135, no. 878. December. 1947. pp. 106-132)

## COOPERATION

20. They did it in Indiana; the story of the Indiana farm bureau co-operatives. Paul Turner. New York, Dryden press, 1947. 159 p. pl. figs.
21. The co-operative challenge. Bertram B. Fowler. Boston, Little, Brown and company, 1947. 265 p.
    The story of the sensational growth of the Consumer cooperative movement.
22. Steps in the establishment of a co-operative economy. P. H. Casselman. (Reprinted from Culture VIII, 1947. pp. 254-262)

## DAIRYING—DAIRY RESEARCH

23. The condition and mutual relationships of calcium caseinate and calcium phosphate in milk, by M. G. Ter Horst; The bacteriological grading of milk by means of the Resazurin test, by J. G. Revallier-Warffemius; The optimum pH for Storch's test, by N. J. M. Vorstman (in Dutch, with English summary); The stability of butter starters, by J. W. Pette (in Dutch, with English summary) (In The Netherlands milk and dairy journal. vol. 1, no. 3. July, 1947. pp. 137-187)
24. Operation and management of milk plants. C. J. Babcock. Wash., 1947. 58 p. figs. tabs. (U.S. Dept. of agriculture circular no. 260, revised)
25. Relative milk production of cows in pen barns and stanchion barns. R. R. Graves and others. Wash., 1947. 7 p. tabs. (U.S. Dept. of agriculture circular no. 763)
26. The utilization of whey. B. H. Webb and E. O. Whittier. Wash., 1947. 3 p. (processed) (U.S. Dept. of agriculture. Bureau of dairy industry. BDIM-Inf-49)

## ECONOMICS

27. Colonial agricultural production; the contribution made by native peasants and by foreign enterprise. Sir Alan Pim. Issued under the auspices of the Royal institute of international affairs. London, Oxford university press, 1946. 190 p. tabs.
28. Federal reserve policy. Karl R. Bopp and others. Wash., Board of governors of the Federal reserve system, 1947. 119 p. figs. tabs. (Postwar economic studies no. 8, 1947)
29. Report of the United States-Syria agricultural mission. Wash., 1947. 99 p. figs. (processed) (U.S. Dept. of agriculture. Office of foreign agricultural relations. International agricultural collaboration series. no. 4)
30. The National institute of economic and social research. Annual report, 1946-7. London, 1947. 24 p.
31. Factory meets farm in North Carolina (a study of the impact of industrialization upon agriculture in Gaston and Davidson counties) Francis E. McVay. Raleigh, 1947. 22 p. figs. tabs. (North Carolina agricultural experiment station. Technical bulletin no. 83)
32. Agriculture in Venezuela. Wash., Pan American union, 1947. 35 p. il. (American agriculture series)

## FEEDING AND FEEDING STUFFS

33. Composition of feeds. Wash., 1947. 33 p. (processed) (U.S. National research council. Committee on feed composition. Report no. 1)
34. Composition of feeds. Vitamin and mineral content. Wash., 1947. 8 p. (processed) (U.S. National research council. Committee on feed composition. Supplement to Report no. 1)
35. Relation between urinary calculi and use of grain sorghum in steer-fattening rations in the Southern Great Plains. W. H. Black and others. Wash., 1947. 14 p. figs. tabs. (U.S. Dept. of agriculture. Technical bulletin no. 945)

## FERTILIZERS

36. Memoranda on colonial fertilizer experiments. I. Planning and conduct of fertilizer experiments. A. B. Stewart. 2. Fertilizer experiments in colonial agriculture. E. M. Crowther. London, H.M. stationery office, 1947. 28 p. (Colonial no. 214)
37. Inspection and analysis of commercial fertilizers. B. D. Cloaninger. Clemson, 1947. 33 p. il. tabs. (South Carolina agricultural experiment station bulletin 369)
38. Optimum soil-nitrate levels for celery, carrots, spinach, onions and beets at different growth levels. John B. Smith and M. Salomon. Kingston, 1947. 27 p. tabs. Rhode Island agricultural experiment station bulletin 300)
39. Organic matter for the garden. Donald Comin. Wooster, Agricultural experiment station. (In Farm and home research bimonthly bulletin. vol. XXXII, July-August, 1947. no. 247)
40. Boron as a plant nutrient; a bibliography of literature published and reviewed January 1941 through December 1941. Catherine M. Schmidt and others. Wash., American potash institute, inc., 1947. 61, xvip. (processed) (Boron supplement IV)
41. Boron for Vermont soils and crops. A. R. Midgley and D. E. Dunklee. Burlington, 1947. 20 p. figs. tabs. (Vermont agricultural experiment station bulletin 539)
42. Onderzoekingen over fosfaat- en kalibemesting op de kleigronden van de zuidhollandsche eilanden. English summary. Investigations on manuring with phosphate and potash on the marine clay soils of the isles in the province of South-Holland. The Hague, 1947. 34 p. figs. (Ministerie van landbouw, visserij en voedselvoorziening. Directie van de landbouw. Verslagen van landbouwkundige onderzoekingen no. 53.5.A)

## FOOD—FOOD PRESERVATION

43. The use of color photography in the experimental freezing of foods. W. B. Cown and T. W. Kethley. Atlanta, 1948. (In Georgia state engineering experiment station circular 18. pp. 9-10, 21-22)
44. Mead-making . . . (In Food, December, 1947. pp. 369-374)
45. Onion juice concentrate prepared by freezing concentration. Frank A. Lee and others. (In The Fruit products journal and American food manufacturer. vol. 27, no. 5, January 1948. pp. 141, 153)
46. International organization in world food crisis. Duncan Wall. (In Foreign agriculture, January, 1948. pp. 3-9)
47. Frozen foods; how to prepare, package, freeze, and cook. Bridgeport, Connecticut, General electric consumers institute, 1947. 31 p. il.

## FORESTS AND FORESTRY

48. Tree-ring hydrology in Southern California. Edmund Schulman. Tucson, 1947. 36 p. figs. tabs. (Arizona. University. Laboratory of tree-ring research. Bulletin no. 4)
49. Trees and the Bible. College Station, 1946. n.p. il. (Texas A. & M. college. Forest service bulletin 37)
50. Trees and shrubs for Eastern North Dakota windbreaks. Fargo, 1947. 4 p. (processed) (North Dakota agricultural college. Extension service circular A-122)
51. Trees and shrubs for Western North Dakota windbreaks. Fargo, 1947. 4 p. (processed) (North Dakota agricultural college. Extension service circular A-123)
52. Management practices for Christmas tree production. C. A. Wellner and A. L. Roe. Missoula, Mont., 1947. 21 p. figs. (processed) (U.S. Dept. of agriculture. Forest service. Northern Rocky Mountain forest and range experiment station. Station paper no. 9)

## HORTICULTURE

53. Flower seed growing in British Columbia. Compiled by J. L. Webster. Victoria, 1947. 73 p. (processed) (British Columbia. Dept. of agriculture. Horticultural branch. Seed production series no. 15)
54. East Malling research station. Annual report, 1946. Maidstone, 1947. 168 p. figs. tabs.
55. The iris; an ideal hardy perennial. Nashville, Tenn., The American iris society, 1947. 224 p. il. pl.
56. Market gardening as a career. J. O. Baker. London, Vawser & Wiles ltd. 96 p. il.

### HORTICULTURE—Continued

57. The apples of England. H. V. Taylor. Foreword by Sir. A. D. Hall. London, Crosby Lockwood & son ltd., 1947. 206 p. col. pl.
58. Black currants; a profitable crop. Charles Robinson. (In Canadian grower, January, 1948. pp. 8-9)
59. House plants. Wm. Godfrey. Ottawa, 1947. 85 p. figs. (Canada. Dept. of agriculture. Publication 798. Farmers' bulletin 145)
60. Hints on dry land gardening. Erdman Braun and Charles Walkof. Ottawa, 1947. 8 p. il. (Canada. Dept. of agriculture. Publication 619. Circular 132. Revision)
61. Ozone in relation to storage of apples. H. A. Schomer and L. P. McColloch. Wash., 1948. 24 p. tabs. (U.S. Dept. of agriculture circular 765)
62. Essais de double greffage sur poiriers. Ph. Aubert. Lausanne, 1947. 11 p. il. (Lausanne. Stations fédérales d'essais viticoles, arboricoles et de chimie agricole, Montagibert. Section d'arboriculture. Publication no. 357)
63. Onion production in Ohio. Donald Comin. Wooster, 1947. 64 p. figs. tabs. (Ohio agricultural experiment station bulletin 671)

### INSECTS—PESTS—INSECTICIDES

64. Insect pests. Wm. Clunie Harvey and Harry Hill. Second edition. London, H. K. Lewis & co., ltd., 1947. 347 p. figs.
65. Household insects and their control. A. V. Mitchener. Winnipeg, 1947. folder. (Manitoba dept. of agriculture and immigration. Publication no. 213)
66. Les traitements antiparasitaires et l'apiculture. Paul Bovey. Lausanne, 1947. 11 p. il. (Lausanne. Stations fédérales d'essais viticoles, arboricoles et de chimie agricole, Montagibert. Section d'entomologie. Publication no. 354)
67. Control of insect pests. St. John's, King's printer, 1946. 16 p. At head of title: Newfoundland. Dept. of natural resources. Agricultural division)
68. Remove leaves with Aero defoliant chemical dust. New York, American cyanamid company, 1947. 21 p. il.
69. Southern pine bark beetles. College Station (1947) 8 p. il. (Texas A. & M. college. Forest service bulletin 33)
70. A laboratory guide in entomology for introductory courses. Robert Matheson. Ithaca, Comstock publishing company, inc., 1947. 135 p. pl.
71. DDT treatments for control of mole-crickets in seedbeds. E. G. Kelsheimer. Gainesville, 1947. 19 p. figs. tabs. (Florida agricultural experiment station bulletin 434)

### LAND SETTLEMENT—LAND TENURE

72. Land settlement in Northeastern Alberta 1943. B. H. Kristjanson and C. C. Spence. Ottawa, 1947. 47 p. figs. tabs. pl. (Canada. Dept. of agriculture. Publication 800. Technical bulletin 63)
73. Kolkhoz (collective farm) in the Soviet Union. Lazar Volin. (In Foreign agriculture. vol. 11, nos. 11-12, November-December, 1947. pp. 146-159)

### LIVE STOCK—BREEDING

74. The cost of keeping a bull compared with artificial breeding. Roy Herman and L. F. Miller. State College, Pennsylvania state college. Agricultural extension service. (In Pennsylvania farm economics. no. 28, 1947. pp. 1-2)
75. Artificial insemination of animals. T. Bonadonna. (In Food and agriculture, the FAO European bulletin. no. 1. August-September, 1947. pp. 16-21)

### MARKETING

76. A survey of the production and marketing of potatoes in Saskatchewan; a preliminary report and summary. (Regina) Saskatchewan department of co-operation and co-operative development, 1947. 11 p. (processed)
77. U.S. Dept. of agriculture. Production and marketing administration. Annual report, 1947. Wash., 1947. 77 p.
78. National association of marketing officials. Report of the twenty-seventh annual convention, 1946. General theme: New marketing history in the making. Oklahoma City, 1947. 92 p.
79. Marketing slaughter livestock in Indiana. D. L. Henry and J. R. Wiley. Lafayette, 1947. 23 p. (Purdue university agricultural experiment station bulletin 522)

## NUTRITION—VITAMINS

80. Butter as a source of vitamin A in the diet of the people of the United States. The Technical committee in charge of the nationwide survey. Wash., 1947. 47 p. (U.S. Dept. of agriculture. Miscellaneous publication no. 636)
81. Calcium and phosphorus in foods and nutrition. Henry C. Sherman. New York, Columbia university press, 1947. 176 p. figs. tabs. bibliography: pp. 119-163.
82. Comparative nutritional values—butter and oleomargarine. Wash. (1947) 4 p. il. (National cooperative milk producers federation. Circular 47-2)
83. Inquiry into the living standard and nutrition among the Jewish urban population of Palestine. G. Cyderovitch and S. Bavly. Jerusalem, 1947. 52 p. tabs.

## PLANT BREEDING

84. Plant growth substances: Some recent applications and further possibilities. J. M. van Stuivenberg. (In Food and agriculture, the FAO European bulletin. no. 2. October-November, 1947. pp. 92-96)
85. Colchicine bibliography. O. J. Eigsti, and Supplement. P. Dustin, jr. (Reprinted from Lloydia, vol. 10, 1947. pp. 65-114)
86. American nutricultural research. F. N. Woodward. (London) 1947. 6 p. (processed) (B.C.S.O. report no. 523. U.K.S.M. memorandum no. 57/47)
87. Seed-bed preparation and cultivation for sugar beets. L. D. Doneen. Berkeley, 1947. 16 p. figs. (California agricultural experiment station bulletin 701)

## POULTRY INDUSTRY

88. Eggs and chickens. Situation in California, 1947. Edwin C. Voorhies. Berkeley, 1947. 24 p. figs. tabs. (California agricultural experiment station circular 374)
89. Duck farming in South Africa. P. J. Serfontein. (In World's poultry science journal. vol. 3, no. 4. October-December, 1947. pp. 227-232)
90. The evolution of the egg. M. A. Khoury. (In Albers egg maker magazine. vol. XXIII, no. 4. Fall, 1947. pp. 5, 17-20)
91. Economic analysis of fourteen years of poultry records. M. F. Abell. Durham, 1947. 31 p. figs. tabs. (New Hampshire agricultural experiment station circular 75)

## PRICES

92. Methodological issues in the theory of price flexibility. D. G. Franszen. (In the South African journal of economics. vol. 15, no. 2. June, 1947. pp. 87-115)
93. The consequences of price control. H. Michell. (In Canadian business. vol. 21, no. 1. January, 1948. pp. 26-27, 62, 63)
94. Prices and expansion. London, National farmers' union. (In The N.F.U. information service. vol. 11, no. 9-10. September-October, 1947)
95. A history of ration banking. J. A. Kershaw. Wash., 1947. 150 p. (U.S. Office of temporary controls. Office of price administration. Historical reports on war administration. General publication no. 2)
96. Where the food dollar goes. E. O. Umsted. (In Marketing activities. November, 1947. pp. 3-10.

## RANGE MANAGEMENT—RANGE VEGETATION

97. Is rotational grazing on native range practical? H. H. Biswell and J. E. Foster. Raleigh, 1947. 17 p. figs. tabs. (North Carolina agricultural experiment station bulletin 360)
98. Nutritional qualities of range forage plants in relation to grazing with beef cattle on the Southern Plains experimental range. D. A. Savage and V. G. Heller. Wash., 1947. 61 p. figs. tabs. (U.S. Dept. of agriculture. Technical bulletin no. 943)
99. Chemical composition of pasture plants . . . J. T. Sullivan and R. J. Garber. State College, 1947. 61 p. tabs. bibliography: pp. 51-61. (Pennsylvania agricultural experiment station bulletin no. 489)

## SEEDS

100. Flaxseed in American farming. Weber H. Peterson. Wash., 1947. 62 p. figs. tabs. (U.S. Dept. of agriculture. Technical bulletin no. 938)

## SERICULTURE

101.¶Sericulture in the world. Rome, International institute of agriculture. Bureau of the F.A.O., 1947. 218 p. tabs. maps. (Studies of the principal agricultural products on the world market no. 8)

102. Les maladies du ver à soie et le contrôle sanitaire des grainages et des educations de reproduction. A. Paillot et A. Rebouillon. Alès, 1945. 85 p. figs. tabs. bibl. pp. 67-77. (France. Ministère de l'agriculture. Bulletin technique séricicole no. 5)

## SOCIAL SURVEYS, RURAL

103. Mobility of rural population: A study of change in residence and occupation in two types of rural communities. Howard W. Beers. Lexington, 1947. 43 p. tabs. (Kentucky agricultural experiment station bulletin 505)

104. Rural family living. Bureau of human nutrition and home economics in cooperation with Bureau of agricultural economics. Wash., 1947. v.p. (processed) (U.S. Dept. of agriculture. Outlook charts 1948)

## SOILS—SOIL CONSERVATION—RECLAMATION

105. Soil survey of Shefford, Brome and Missisquoi counties in the province of Quebec. D. B. Cann, P. Lajoie, and P. C. Stobbe. Joint publication of Experimental farms service, Dominion department of agriculture in co-operation with the Quebec department of agriculture and Macdonald college, McGill university. Ottawa, King's printer, 1947. 84 p. figs. tabs. col. maps.

106. De karakteriseering van de granulaire samenstelling van gronden. English summary. The characterisation of the mechanical composition of soils. W. C. Visser. The Hague, Ministerie van landbouw, visserij en voedselvoorziening directie van de landbouw, 1947. 45 p. figs. tabs. (Verslagen van landbouwkundige onderzoekingen no. 53.7.A)

107. Soil fertility. P. D. Caldis. (In Food and agriculture of the United Nations. Report of the FAO mission for Greece. Appendix D. pp. 134-140)

108. Saving soil. I. T. Dietrich. Fargo, 1947. 27 p. il. (processed) (North Dakota agricultural college. Extension service special circular A-111)

109. British Columbia agrologists act. British Columbia institute of agrologists by-laws. (In Agricultural institute review. vol. 2, no. 6. November, 1947. pp. 422-431)

110. The soil saving 7 for Washington's wheatland. Pullman, 1947. folder. il. (Washington. State college. Institute of agricultural sciences. Extension circular no. 117)

111. The agricultural use of peat materials. A. A. Swinnerton and P. O. Ripley. A cooperative publication of the Departments of agriculture and Mines and resources. Ottawa, 1947. 15 p. figs. (Canada. Dept. of agriculture. Publication no. 803. Farmers' bulletin 147)

112. The soils of Fulton county, Pennsylvania; their origin, classification and use. State College, 1947. 102 p. figs. maps. (Pennsylvania agricultural experiment station bulletin 487)

113. Soil management practices, Quitman county. C. G. Morgan and H. B. Vanderford. State College, 1947. 37 p. figs. (Mississippi agricultural experiment station bulletin 447)

114. How reclamation pays: A book of project repayment histories and payout schedules with history of crop production. Wash., U.S. Dept. of the interior. Bureau of reclamation, 1947. 335 p. figs. tabs.

115. Crop adaptation to soils of varying acidity or alkalinity. H. J. Harper. Stillwater, 1947. 15 p. tabs. (Oklahoma agricultural experiment station bulletin 316)

116. Soil reaction and availability of plant nutrients. H. J. Harper. Stillwater, 1947. 11 p. tabs. (Oklahoma agricultural experiment station bulletin 315)

117. Acid soils in Oklahoma; where they are located, and how they form. Horace J. Harper. Stillwater, 1947. 29 p. figs. (Oklahoma agricultural experiment station bulletin 313)

118. Soil drift control on Mallee farms. Seventh annual competition 1946-47. Report of the judge, R. G. Thomas. Victoria, Soil conservation board, 1947. 15 p. il.

119. Carbon-nitrogen ratios of grass mulches. C. H. Diebold. Albuquerque, New Mexico, 1947. 7 p. (processed) (U.S. Dept. of agriculture. Soil conservation service. Region six. Regional bulletin no. 104. Soil series no. 10)

## STATISTICS

120. Statistical abstract of the United States. Sixty-eighth edition, 1947. Wash., U.S. Dept. of commerce. Bureau of the census, 1947. 1038 p.
121. Canada year book, 1947. Ottawa, King's printer, 1947. 1239 p. maps. diagrs. At head of title: Canada, Dept. of trade and commerce. Dominion bureau of statistics.
122. County data book; a supplement to the Statistical abstract of the United States. Wash., U.S. Dept. of commerce. Bureau of the census, 1947. 431 p. (processed) (80th Congress, 1st session. House document no. 340)
123. Special report of multiple-unit operations in selected areas of the Southern States. Units, subunits, acreage, value characteristics, specified crops and livestock and value of farm products. Wash., U.S. Dept. of commerce. Bureau of the census, 1947. 638 p. (U.S. census of agriculture, 1945)
124. A conspectus of the province of Ontario. Prepared by the Ontario bureau of statistics and Research department of the provincial treasurer. Toronto, King's printer, 1947. 422 p. tabs. col. maps.
125. Grapes and grape products. Wash., U.S. tariff commission, 1947. 73 p. (processed) (War changes in industry series. Report no. 24)
126. Synthetic organic chemicals: United States production and sales, 1946. Preliminary. Wash., U.S. tariff commission, 1947. 54 p. (processed)

## TARIFF—TAXATION

127. United States tariff commission. Thirty-first annual report, 1947. Wash., 1947. 66 p.
128. United Nations general agreement on tariffs and trade. Lake Success, N.Y., 1947. 4 vols. v.p. (processed)
129. Prairie farmers income tax guide and farm account book. Issued by Taxation division, Department of national revenue. Ottawa, King's printer, 1947. 43 p. (English and French texts)
130. Farmers income tax guide and farm account book. Issued by the Taxation division, Department of national revenue. Ottawa, King's printer, 1947. 45 p.
131. The income tax bill; a review and analysis. Toronto, Canadian tax foundation, 1947. 19 p.

## TEXTILES

132. Stress relaxation of cotton and rayon cords at constant length. E. G. Burleigh and Helmut Wakeham (Southern regional research laboratory, New Orleans, La.) (Reprinted from Textile research journal, vol. XVII, no. 5, May, 1947. pp. 245-255) (U.S. Dept. of agriculture. Bureau of agricultural and industrial chemistry. AIC-172)
133. The significance of certain textiles found at Redbank, New Brunswick, in relation to the history of the culture area. W. S. Hadlock. (In Acadian naturalist, vol. 2, no. 8, July, 1947. pp. 49-66)
134. Effects of some environmental factors on the seed and lint of cotton. Auburn, 1947. 87 p. tabs. (Alabama polytechnic institute. Agricultural experiment station bulletin no. 263)
135. Women's preferences among selected textile products. Wash., 1947. 124 p. tabs. (U.S. Dept. of agriculture. Miscellaneous publication no. 641)

## TOBACCO

136. Principles of burley tobacco barn operation. Lester S. O'Bannon. Lexington, 1947. 68 p. figs. tabs. (Kentucky agricultural experiment station bulletin 501).
137. Contribution à l'étude de l'amélioration des tabacs indigènes. II. J. Stalé et E. Bovay. Berne, Imprimerie fédérative S.A., 1947. pp. 225-249. Lausanne. Stations fédérales d'essais viticoles, arboricoles et de chimie agricole. (Publication no. 355) (Tirage à part de l'Annuaire agricole de la Suisse 1947)
138. 1947 world tobacco prospect improves. Wash., 1947. 5 p. (processed). (U.S. Dept. of agriculture. Office of foreign agricultural relations. Foreign agriculture circular FT 8-47)
139. Statistical handbook of Canadian tobacco. Ottawa, Dominion bureau of statistics. Agricultural division, 1947. 45 p. tabs. charts. (processed)

## VETERINARY MEDICINE

140. Diseases of poultry; their aetiology, diagnosis, treatment and control, with a section on the normal anatomy and physiology of the fowl. Ernest Gray. London, Crosby Lockwood & son ltd., 1946. 200 p. il.
141. Recent advances in clinical pathology. General editor, S. C. Dyke. Produced under the auspices of The European association of clinical pathologists. London, J. & A. Churchill ltd., 1947. 468 p. pl. References at ends of chapters.
142. Ketosis in domestic animals; clinical and experimental observations. Jesse Sampson. Urbana, 1947. (Illinois agricultural experiment station bulletin 524)
143. Common external parasites of chickens and turkeys. The Poultry council of the State college of Washington. Pullman, 1947. 12 p. il. (Washington state college. Agricultural extension bulletin no. 370)

## WEEDS

144. Agricultural uses of selective herbicides. T. K. Pavlychenko. (Saskatoon), University of Saskatchewan. Research laboratory of plant ecology, 1947. 13 p. tabs. (processed)
145. Ce merveilleux 2, 4-D. Richard Cayouette. (Extrait de Agriculture, vol. IV, no. 1, mars 1947)
146. IPC and quack grass control. R. F. Carlson. (In Better farming methods, February, 1948. p. 22)
147. Bindweed eradication in Oklahoma. Wesley Chaffin. Stillwater, n.d. 7 p. (Oklahoma A. and M. college. Extension service circular 453)

## ZOOLOGY

148. Clearing and staining small vertebrates, in toto, for demonstrating ossification. H. E. Evans. (In Turtox news. vol. 26, no. 2, February, 1948. pp. 42-47)

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The following publications are needed in the library:

Indiana A.E.S. cir. 316.
New Hampshire A.E.S. bul. 370.
Virginia. Dept. of agriculture and immigration. Bulletins 448 and 449.
South Dakota A.E.S. cir. 66.